# AN ANALYSIS OF THE IMPACT OF BASE SUPPORT RESOURCES ON THE AVAILABILITY OF AIR MOBILITY COMMAND AIRCRAFT

THESIS

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## Abstract

Over the past decade, the nation's military has grown increasingly reliant upon strategic airlift capability. In the post-Cold War era, military doctrine has shifted from an inventory policy favoring overseas basing and prepositioned materiel to a transportation policy that concentrates on the rapid deployment of forces. Much of the responsibility for providing timely global mobility belongs to the Air Mobility Command (AMC) and its fleet of strategic cargo aircraft. Despite the emphasis that has been placed on strategic airlift capability, several recent studies indicate the DoD may possess insufficient lift capacity to meet current theater requirements.

The AMC Directorate of Logistics is responsible for ensuring AMC aircraft are available to accomplish the mission. Currently, however, the organization lacks an objective tool for assessing the impact of proposed operations on the health of the fleet. To improve this process, the Directorate has initiated the development of a Mobility Aircraft Availability Forecast (MAAF) simulation model designed to identify alternatives and associated impacts on aircraft availability, manpower, and cost.

This research seeks to assist the MAAF development effort by identifying and demonstrating how different base support factors impact the availability of AMC aircraft. To address this research objective, multiple simulation models were developed using the Airfield Simulation Tool (AST). The impact of changing resource levels was assessed for different locations and aircraft arrival profiles. Results of this research yield practical implications for developers of the MAAF model and air mobility planners.

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Christian E. Randall

## Table of Contents

Page

## List of Figures

# List of Tables

Page

Page

AN ANALYSIS OF THE IMPACT OF BASE SUPPORT RESOURCES ON THE AVAILABILITY OF AIR MOBILITY COMMAND AIRCRAFT

# I. Introduction

## Background

Over the past decade, the nation's military has grown increasingly reliant upon strategic airlift capability. Changes in the international security environment prompted a shift in military doctrine that deemphasizes forward basing, and relies instead upon the ability of continental U.S. (CONUS)-based forces to quickly establish a forward presence (Air Force Doctrine Document 2-6.3, 1999:1). The 2001 Quadrennial Defense Review suggests that military planners should concentrate on a 'capabilities-based' model as opposed to the former 'threat-based' model typical of the Cold War era (Department of Defense, 2001:13). The emergence of an asymmetric threat, combined with congressionally mandated force reductions, have prompted the Department of Defense (DoD) to exchange considerable infrastructure and prepositioned war materiel in favor of a rapidly deployable force. The burden of providing this timely global mobility falls chiefly upon the Air Mobility Command (AMC), a U.S. Transportation Command component responsible for providing airlift, air refueling, special air mission, and aeromedical evacuation of U.S. forces. Despite the emphasis that has been placed on strategic airlift, however, recent studies indicate the DoD possesses insufficient lift

capacity to meet current theater commander requirements (Department of Defense, 2001:8; General Accounting Office, 2000:5). Given the demand for strategic airlift and potential capacity shortfall, AMC must attempt to employ its mobility fleet in the most efficient manner possible.

The AMC Directorate of Logistics is responsible for ensuring AMC aircraft are available to accomplish the mission. The Directorate develops the concepts and manages the logistics support necessary to ensure the operation of AMC assets in peacetime and during contingencies. Currently, the Logistics Directorate lacks the capability to assess alternatives to AMC decision-making processes (Nelson, 2003:1). Aircraft scheduling to meet theater contingency needs and peacetime requirements, therefore, is often based on the experience of the individuals involved in the process rather than through objective analysis of various alternatives. In an effort to improve this process, the Directorate has initiated the development of a Mobility Aircraft Availability Forecast (MAAF) simulation model designed to identify alternatives and associated impacts on aircraft availability, manpower, and costs (Nelson, 2003:1). Implementation of this forecasting tool is expected to contribute to increased scheduling efficiency with regard to selection of strategic lift assets.

**Problem Statement**

The effectiveness of the proposed MAAF simulation model will depend largely upon the ability of model developers to accurately identify and capture the factors that contribute to aircraft availability within AMC. The ability of the model to predict the number of aircraft available for worldwide missions relies in part on an understanding of the relationship between base support resources and aircraft availability. This research

seeks to identify those base support functions and resources that contribute significantly to the availability of AMC aircraft. The study will examine the sortie generation process from a supply-side perspective.

### Research Objective

The primary objective of this research is to identify and demonstrate how different variables related to base support capability impact Air Mobility Command aircraft availability.

### Investigative Questions

In order to address the high-level research objective, this research examines the relationship between base support resources and aircraft availability by addressing the following investigative questions:

1. What is the history regarding the study of aircraft availability within the Air Force?
2. What is the nature of the current process used by AMC to create available strategic cargo aircraft?
3. What base support factors impact the availability of strategic cargo aircraft?
4. What are the relationships between important base support factors?

### Methodology

This study uses two general approaches for addressing the research objective. A comprehensive review of existing literature was conducted to help define the construct of aircraft availability. To understand the AMC process for ensuring the availability of strategic cargo aircraft, this study also investigated current AMC policies and procedures.

The review of the literature resulted in the identification of base support functions and resources that significantly impact the availability of AMC aircraft.

An existing simulation model, the Airfield Simulation Tool, was used to describe the relationship between base support factors and aircraft availability. Aerial port activities at two en route locations, Ramstein Air Base and Naval Air Station (NAS) Sigonella, were modeled to produce estimates of the number of aircraft each airfield could generate. The experimental design used for this study was a $2^4$ full factorial design in which two levels (high and low) of four distinct factor categories were assessed. This design was repeated for three aircraft arrival mixes (C-5 only, C-17 only, C-5/C-17 mix) at two different locations, for a total of six experiments. The $2^k$ factorial design provided the capability to measure interaction between important factors, allowing main effects and interactions to be assessed independently.

**Scope and Limitations of the Research**

The Air Mobility Command mobility fleet consists of several types of aircraft, including cargo airlift, tanker, and aeromedical. The base support factors influencing the availability of these various aircraft types may be heterogeneous in nature. This research, therefore, will focus on the impacts of base support factors as they relate to the availability of C-17 and C-5 aircraft. Furthermore, this research will be constrained to those factors that are related to base support resources and conditions impacting aircraft availability. Consideration of other potentially confounding variables will be recognized, but not evaluated for the purposes of this effort.

This design of experiments represents a "fixed effects" model because factor levels were not randomly assigned, but were purposefully selected. As such, results of

the analysis may not be generalized beyond the particular values selected for the experiment (Kachigan, 1991:212).

**Chapter Summary**

This chapter discussed the background, the problem statement, the research and investigative questions, the methodology, and the scope and limitations of the research effort. The subsequent chapters include the Literature Review, Methodology, Analysis and Results, and Conclusions and Recommendations.

The literature review examines the concept of aircraft availability and the base support resources that influence the availability of mobility aircraft. A conceptual framework is developed involving the recent history of strategic airlift and the current air mobility network. The concept of aircraft availability and several measures of the term are discussed. Lastly, airfield capacity and the factors identified in the literature as being critical to increasing airfield capacity are presented.

Chapter three describes the procedures used in this study to investigate the relationship between base support resources and aircraft availability. A complete methodology is presented, including a discussion of previous approaches used to study airfield capacity, a review of the Airfield Simulation Tool employed in this study, and a description of the design of experiments developed to investigate the research objective.

Chapter four presents an analysis of the simulation results obtained during the implementation of the experimental procedures. Output analysis issues are examined, including desired simulation run lengths and number of replications for each design point. Additionally, chapter four will present statistical analysis of simulation results and evidence that appropriate statistical assumptions have been satisfied.

Chapter five presents a summary of the results and findings of this study. The research objective and each of the investigative questions will be addressed and supported.

# II. Literature Review

## Chapter Overview

This purpose of this chapter is to discuss existing literature with respect to the study of aircraft availability and the impact base support resources have upon the availability of mobility aircraft. Background concerning the recent history of strategic airlift is presented to highlight the significance of using airlift efficiently given the current global mobility environment. An overview of the current air mobility network is provided to describe the structure of the network and the relationship between air mobility bases that influence an airfield's capacity to service aircraft. The concept of aircraft availability is discussed, and several measures of the term are presented. The subsequent discussion examines the concept of airfield capacity and some of the common methods by which the capacity of airfields has been assessed. Lastly, the factors identified in the literature as being critical to increasing airfield capacity, and thereby improved aircraft availability, are presented.

## Background

In the post-Cold War era, rapid projection of US military force has become the predominant military strategy. Changes in the international security environment have prompted a shift in military doctrine that deemphasizes forward basing, and relies instead upon the ability of CONUS-based forces to quickly establish a forward presence (Air Force Doctrine Document 2-6.3, 1999:1). Rather than stockpile large quantities of inventory in the form of infrastructure, prepositioned materiel, and parts, the new strategy emphasizes rapid deployment and resupply of forces using strategic mobility assets.

Rapid global mobility, a core competency of the Air Force, is a key enabler of this new strategy. The burden of providing timely deployment and sustainment of military force falls chiefly upon the airlift forces operated by the Air Mobility Command (AMC). As the Air Force component of the U.S. Transportation Command, AMC is the single manager for air mobility responsible for providing airlift, air refueling, special air mission, and aeromedical evacuation of U.S. forces. Despite the emphasis on strategic airlift capability, recent studies indicate the Department of Defense possesses insufficient lift capacity to meet current theater commander requirements (Department of Defense, 2001:8; General Accounting Office, 2000:5). Given the demand for strategic airlift and potential capacity shortfall, AMC must employ its mobility fleet in the most efficient manner possible.

**The Air Mobility System**

An air mobility network has been established to enable mobility air forces to efficiently and effectively meet worldwide deployment and sustainment air transportation requirements. The air mobility system is an integrated system that incorporates all aspects of intertheater and intratheater airlift needed to deliver personnel, cargo, and/or patients at the proper time and place (Air Force Doctrine Document 2-6.3, 1999:13). The key components of the network include a command and control element, CONUS-based flying wings, and the Global Air Mobility Support System (GAMSS). These components combine to provide the flexibility and responsiveness necessary to support a variety of delivery options. The traditional approach to delivering payloads involves an employment concept referred to as a “hub and spoke” operation. Using this method, an air bridge is developed over which strategic cargo aircraft transport payloads between

CONUS-based Aerial Ports of Embarkation to intermediate staging areas, hubs, in overseas theaters. From these locations, cargo is transferred onto smaller, tactical airlift aircraft for movement to designated forward operating locations. With the introduction of the C-17 and its unique capabilities, a new employment concept, direct delivery, has been developed that bypasses traditional hubs and eliminates the need for intermediate staging areas (Cook, 1998:1). The subsequent discussion examines the components of the air mobility system.

To promote efficiency and effectiveness of worldwide operations, air mobility operations rely on the principal of centralized command and control. The AMC Tanker/Airlift Control Center (TACC) is the agency responsible for tasking and control of all AMC operations. Through its command and control system, TACC is able to continuously schedule, task, manage, coordinate, control, and execute air mobility missions around the globe (Air Force Doctrine Document 2-6, 1999:16). Additionally, the agency is able to track the status and location of cargo and personnel throughout the transportation network. The ability to establish and maintain in-transit visibility of assets in motion has become critical as the military has transitioned to a leaner, more expeditionary force.

Although command and control of mobility operations is centralized, the actual execution of the mobility mission is managed at the operational level. Flying wings located at permanent, stateside bases typically execute the mobility mission. Much of the logistics work associated with the mobility mission (i.e., unscheduled maintenance, depot scheduling, aircraft tasking) is accomplished at home station locations.

The GAMSS represents the support backbone of global mobility. The GAMSS network facilitates large-scale mobility operations through an integrated system of garrison units and deployable support forces (Briggs, 2003). With its ability to expand and contract, GAMSS provides responsive aircraft servicing and cargo handling that enables seamless operations between garrison locations and austere environments (Air Force Doctrine Document 2-6.3, 1999:2). The support system is comprised of fixed, en route bases positioned at key locations around the globe (see figure 1), and CONUS-based deployable forces that augment garrison units during periods of increased operational activity.


**Figure 1. Map of AMC en route locations**

The fixed en route system provides limited support to AMC aircraft, including command and control, passenger and cargo processing, aircraft serving, and aircraft

maintenance. The level of aircraft maintenance capability, defined as major, minor, and limited, varies between en route locations (Air Mobility Command, 2003a:2). A location possessing limited maintenance capability can accommodate basic aircraft servicing/troubleshooting needs. Minor en route capability enhances limited maintenance by incorporating additional line replaceable unit remove/replace actions and limited backshop repair capability. Minor en route stops provide the capability to restore functionality of mission critical systems as defined by the Minimum Equipment Listing (MEL). The items listed on the MEL for a specific mission design series (i.e., C-5, C-17) represent minimum restrictions only. Major en route locations offer the maintenance capabilities listed above, as well as more in depth troubleshooting and enhanced backshop support. While the bulk of the AMC maintenance effort takes place at home station (Briggs, 2003), the en route structure provides a predictable level of aircraft maintenance support needed to sustain air mobility commitments (Air Mobility Command, 2003:1).

To accommodate periods of increased operational activity, the GAMSS network consists of a large, deployable component, the Global Mobility Task Force (GMTF). Organized under two Air Mobility Operations Groups, tailorable pools of resources are maintained within the GMTF to augment existing permanent locations and expand the air mobility network when needed (Air Force Doctrine Document 2-6.3,1999:14).

This section has described the air mobility system. The base support functions and resource levels associated with a particular location may vary depending on its purpose and placement within the mobility network. Most logistics functions are accomplished at stateside bases, although en route locations are considered critical to the

sustainment of mobility operations.  The following discussion examines the concept of aircraft availability.

**Aircraft Availability**

While the air mobility network provides the support needed to satisfy worldwide airlift requirements, perhaps the key factor constraining Mobility Air Forces is the availability of strategic aircraft to perform their assigned missions.  AMC's determination of the airlift requirement and the ability of existing strategic airlift resources to meet the requirement are based on the expected availability of aircraft (General Accounting Office, 2000:10).  Although aircraft availability is a critical element of air operations, Joint Publication 1-02, the Department of Defense Dictionary of Military and Associated Terms, provides no precise definition of the term.  The characterization of aircraft availability has chiefly become dependent upon the organizational setting in which it is used.  While a variety of definitions exist, fleet availability indicators typically measure the ability of logistics to provide the aircraft needed to meet mission requirements (Air Force Logistics Management Agency, 2001:14)  Some of the more common descriptions of aircraft availability are reviewed in the subsequent discussion.

***Mission Capable Rate.***

Historically, the Air Force has used aircraft mission capable (MC) rates as the yardstick by which health of the fleet and availability of aircraft are measured.  Joint Publication 1-02 (2003:342) defines mission capability as "the material condition of an aircraft indicating it can perform at least one and potentially all of its designated

missions." The percentage of possessed hours that an aircraft is in a mission capable state is known as the MC rate (Air Force Logistics Management Agency, 2001:25). MC rate, a lagging indicator, uses historical data to highlight trends related to aircraft mission readiness. Because these rates represent a composite of many processes and metrics, other fleet availability indicators must be used to perform root cause analysis when MC rates decline (Air Mobility Command, 2003b:32). For example, low MC rates may be driven by long maintenance servicing times, spare parts shortages, training deficiencies, high commitment rates, and/or poor prioritization. MC rate provides an assessment of aircraft availability from an aircraft maintenance standpoint.

***Supply Availability.***

In contrast to the MC Rate perspective, a supply viewpoint asserts "an aircraft is operationally available if not waiting for a reparable component to be repaired or shipped" (Kapitzke, 1995:8). This approach views the aircraft as a serial system, and assumes all components must be working for the end item to be considered available. Aircraft availability from a supply standpoint can be estimated by calculating the probability of an aircraft missing an item. Supply availability (A) is expressed mathematically by the following formula:

$$A = \prod_{i=1}^{I} \left[ 1 - \frac{\left(EBO(S_i)\right)}{NZ_i} \right]^{Z_i} \qquad (1)$$

where *i* is the ith item at a random point in time, $EBO(S_i)$ represents the probability of an expected backorder for item *i* given inventory quantity S, N is the number of aircraft in the fleet, and $Z_i$ stands for the quantity of item *i* per aircraft. The Multi-Echelon

Technique for Reparable Item Control (METRIC) family of models used frequently within the Air Force incorporate this mathematical approach to minimize expected backorders or maximize weapon system availability (Zorn, 1996:14). The Aircraft Availability Model, for instance, computes optimal levels of spare parts necessary to attain established aircraft availability goals.

***MAAF Availability.***

While these previous definitions of aircraft availability may adequately serve their intended purpose, they do not properly address the short term, point-in-time status of aircraft necessary to support certain AMC decisions. MC Rate and supply perspectives of aircraft availability are typically more appropriate for supporting strategic decisions related to weapon system acquisition and policy. To support development of the MAAF model, however, a short-term definition of aircraft availability is necessary. This study defines aircraft availability as "the number of aircraft available at any time to perform a specific airlift mission or category of airlift missions based on all pertinent operational and logistics factors" (Goddard, 2003). According to this definition, therefore, an aircraft is considered available if it is capable of performing the mission to which it is currently assigned.

This section has discussed some of the previous approaches by which the concept of aircraft availability has been investigated. MC Rate is a lagging indicator of the health of the fleet. Supply availability is a mathematical approach for determining appropriate levels of reparable spares for a weapon system. Because these perspectives offer a strategic view of aircraft availability, a short-term definition was provided that supports

this study and development of the MAAF model. The next discussion examines the influence of airfield capacity on the availability of mobility aircraft.

**Airfield Capacity**

The number of aircraft available to perform specific missions depends in part on the capabilities of airfields to restore aircraft to mission ready status. Estimates of airfield capacity are necessary to support both long-term mobility force structure studies and near-term operational planning (Stucker and Berg, 1998:1). When an airfield's resources become over-burdened, the location may form a bottleneck in the air mobility network that effectively limits the airlift capacity of the mobility fleet. Therefore, strategic mobility planners need accurate estimates of airfield capacity to support aircraft investment decisions and development of resource allocation plans. During contingency operations, planners need to know point in time capability of airfields to handle transiting airflow based on current resource quantities. Despite the critical nature of understanding airfield capacity, the concept has historically been difficult to define and perhaps more difficult to measure. Part of the challenge in determining airfield capacity lies in the stochastic nature of the quantities and availabilities of the many resources required to support air mobility operations.

Air Force doctrine asserts that global mobility support is a system dependent on resources (Air Force Doctrine Document 2-6.3, 1999:31). Congressionally mandated funding and force structure constraints limit the quantity of resources available to the air mobility network. The fact that airfields possess limited space and finite quantities of critical resources restricts the number and types of aircraft that a particular location can service (Morrison, 1996:1). The efficiency and effectiveness of mobility operations,

therefore, are constrained by the degree to which resources are allocated throughout the air mobility network. For example, a 1996 mobility study of a major Southwest Asia deployment found that resource shortages at en route locations reduced the amount of cargo delivered by roughly 20% from what could have been moved if those shortages did not exist (Stucker & Williams, 1999:v).

The personnel, equipment and infrastructure needed to support mobility operations perform a multitude of functions. An airfield's mobility resources are typically used to prepare aircraft, aircrews, passengers, and cargo loads for movement from points of origin, through en route locations, to destinations (Morrison, 1996:5; Stucker and Berg, 1998:1). In broad terms, airfield capacity refers to the ability of a mobility airfield to satisfy aircraft demands for resources. Arriving aircraft place demands for resources on an airfield in terms of a need for space (parking) and for servicing (Rodin, 1998:1). The following discussion examines some of the efforts taken to characterize the relationship between resources and airfield capacity.

***Recent Airlift Studies.***

Several major mobility studies over the past decade have examined the impact of airfield capacity on airlift operations. The Revised Intertheater Mobility Study conducted by the Joint Staff in the late 1980s expressed airfield capacity as the number of sorties per day by aircraft type (Stucker and Williams, 1999:8). Ramp space was the only airfield resource modeled for this effort, since it was assumed all other resources could reasonably be augmented until they were no longer constraining elements.

The Mobility Requirements Study (MRS) used an optimization model to estimate airlift capacity. Although the MRS was more comprehensive than previous studies in

terms of the types of airfields examined and types of aircraft modeled, airfield capacity still depended solely on the availability of ramp space (parking). Airfield capacity was again expressed as sorties per day. The MRS Bottom-Up Review Update (BURU) conducted in 1994 included fuel as a constraining airfield resource in addition to ramp space. MRS BURU also differentiated aircraft ground service times according to mission profile (i.e., quick-turn, full service). Although emphasis on airfields had increased, the study still generally failed to recognize the constraining impact of an airfield's resources on airlift capacity (Stucker and Williams, 1999:10).

Initial methods for estimating airfield capacity typically involved three items of information related to a particular airfield:

1. The number of aircraft ($x$) that could be simultaneously serviced given an airfield's existing resources.
2. The number of hours per day ($y$) that those resources were available.
3. The average amount of time ($z$) that an aircraft demanded of an airfield's resources in order to complete servicing.

Single, specific estimates for these three variables resulted in single, ambiguous values of an airfield's capacity (Stucker and Berg, 1998:5). To obtain more explicit results, several capacity estimates could be calculated by varying attributes between different aircraft. By distinguishing between wide-body and narrow-body aircraft, for example, a set of values of airfield capacity could be determined. This approach forms the basis for calculating maximum on ground.

***Maximum on Ground.***

Airfield capacity has commonly been estimated using a measurement called maximum on ground (MOG) (Williams,1999:4). Many people with mobility experience are familiar with the term, but its precise meaning varies between personnel from different functional specialties. A single definition of MOG is perhaps not practical due to the number and complexity of factors that contribute to the measurement. Air Force Pamphlet 10-1403, Air Mobility Planning Factors (Department of Defense, 1998:24), describes MOG as “the maximum number of aircraft which can be accommodated at an airfield”. This basic definition typically refers to the parking capacity of an airfield. More specialized definitions of MOG are necessary to accurately describe the relationship between all of an airfield’s critical resources and different types of aircraft. An overall MOG planning factor for each particular aircraft type at each particular location must generally be determined from the most limiting of an airfield’s resources (Williams, 1999:7). Because the utilization of resources is continually changing, determining the constraining resource, which ultimately limits the airfield’s capacity, is a challenge. A definition of MOG commonly used in the mobility community that incorporates many of the constraining factors is “the maximum number of aircraft on the ground that can land, taxi-in, park, be unloaded, refueled, maintained, inspected, loaded, taxi-out, be cleared for departure, and takeoff within a planned time interval” (Williams, 1999:5; Morrison 1996:8).

When measuring an airfield’s capacity with respect to MOG, analysts typically refer to the maximum number of aircraft that can be physically parked (parking MOG) or serviced (working MOG) at an airfield over a given amount of time. Parking MOG considers the weight bearing capacity of aircraft maneuvering areas, taxiway widths,

runway lengths, and size and shape of the parking ramp (Morrison, 1996:11). An airfield's parking capacity is dependent on the footprint (size and weight) of each type of aircraft involved in an operation. Parking capacity is the primary consideration given to airfield capacity estimates because it is the most difficult resource to augment (Stucker and Berg, 1998:9).

Adequate parking is not the only consideration when estimating the capacity of an airfield. The combination of resources required to service an aircraft so that it can continue its mission is known as "working MOG". This concept assesses the capability of an airfield to conduct refueling, servicing, maintenance, and cargo loading/unloading (Williams, 1999:4).

The purpose of the MOG measurement is to determine an airfield's constraining resource. The identification of this limiting factor provides planners with a reliable estimate of the capacity of the airfield to recover, service, and launch aircraft. The degree to which MOG values are accurate depends on the planner's ability to identify and quantify those airfield resources critical to the process.

***Airfield Throughput Capability.***

Another approach to measuring airfield capacity is a metric called "airfield throughput capability". As defined by AFPAM 10-1403 (Department of Defense, 1998:23), the throughput capability of an airfield is "the amount of cargo and passengers which can be moved through the airfield per day via strategic airlift based on the limitations of the airfield". This measurement uses predetermined values of MOG, aircraft payloads, base operating hours, and service ground times to calculate the amount

of cargo an airfield is capable of processing per day. Airfield throughput capability (ATC) is represented by the following formula:

$$ATC = \frac{(MOG) \times (average\ payload) \times (operating\ hours)}{(ground\ service\ time)} \times (85\%\ queuing\ efficiency) \quad (2)$$

where MOG represents the lower of either the airfield's working or parking MOG. Using aircraft-specific values for payload and ground service time as provided by AFPAM 10-1403, mobility planners can make gross estimates regarding the capacity of airfields to handle given amounts of personnel and material. For example, the following scenario examines a particular airfield's capability to process arriving C-17 aircraft. According to AFPAM 10-1403 the average cargo payload of the C-17 is 45 short tons, and its average ground time when requiring refueling and reconfiguration is two hours and fifteen minutes. If the particular airfield supports 24-hour operations and possesses a MOG value of two, then the location's airfield throughput capability can be estimated as

$$ATC = \frac{2 \times 45 \times 24}{2.25} \times .85 = 816\ short\ tons\ of\ cargo\ per\ day \quad (3)$$

If the planner's expected throughput exceeded this airfield's estimated capability, then the flow would have to be reduced or the airfield's limiting resources would have to be increased to accommodate the higher demand.

***RAND Definition of Airfield Capacity.***

Despite the increased attention given to estimating airfield capacity over the past decade, the measures of an airfield's capacity discussed to this point have been criticized

for inadequately considering the multitude of problems and uncertainties associated with the servicing of mobility aircraft (Stucker and Berg, 1998:6). Critics charged that inflated estimates of airfield capability were contributing to overly optimistic estimations of the nation's airlift capacity. In response to this criticism, the Force Protection Directorate in the Office of the Secretary of Defense funded a study by RAND's National Defense Research Institute that sought to improve the DoD's understanding of airfield capacity. RAND analysts Stucker and Berg (1998:2) define airfield capacity as "the maximum number of missions that can be routed through and supported by a particular airfield during a 24-hour day, given specified resources". This definition, by emphasizing missions as opposed to aircraft, more accurately recognizes the notion that certain exogenous variables influence the capacity of an airfield. A "mission" involves aircraft type, aircraft configuration, mission profile (quickturn versus full service stop), and servicing requirements. Airfield capacity then refers not to a single number, but to a range of capabilities representing potential combinations of missions through a particular location. Thus, the capacity of the airfield changes in response to changes in the variety of missions and to changes in the quantities of available resources. Stucker and Berg (1998:8) describe the basic relationship between an airfield's resources and the airfield's capacity as:

$$C = Min\ (R_i * A_i / S_i) \qquad over\ i = 1,\ldots,n \tag{4}$$

where $C$ reflects the capacity of the resources at a particular airfield expressed as the number of aircraft assigned a particular mission that can be serviced in a 24-hour period. $R_i$ represents the quantity of resource $i$ available at the location, $A_i$ represents that

number of hours per day that resource *i* is available, and $S_i$ stands for the time required of resource *i* in servicing a single aircraft.

This section has described previous measures and definitions for airfield capacity. In each case, the validity of the measure is dependent on the identification and quantification of resources critical to the servicing of aircraft. The following discussion examines the factors that significantly impact the capacity of mobility airfields.

**Factors Affecting Airfield Capacity**

In broad terms, the factors that influence an airfield's ability to accommodate and service aircraft are well documented. Primary considerations fall into one of four categories: maintenance capability, material handling equipment (MHE), airfield characteristics, and petroleum, oils, and lubricants (POL) (Air Force Doctrine Document 2-6.3, 1999:31; Williams, 1995:5; Stucker and Berg, 1998:12). The following discussion examines each of these categories in greater detail.

***Maintenance Capability.***

An airfield's capacity is largely dependent on the number of maintenance personnel and the amount of maintenance equipment assigned there. A mobility base must have sufficient manpower to perform tasks such as aircraft marshalling, inspection, servicing, and maintenance. As an indicator of the importance of manning levels within the air mobility network, for example, the Air Force Personnel Center recognizes en route locations as 100% manning points, which guarantees maintenance manning levels very close to 100% (Air Mobility Command, 2003a:5).

Not only are the number of personnel important, but the experience of those personnel is also a concern. At en route locations, for example, AFPC selectively assigns

personnel to meet a 50% Special Experience Identifier match to ensure maintenance personnel possess necessary experience related to cargo aircraft (Air Mobility Command, 2003a:5). In addition, maintenance personnel at these locations must hold at least a 5-skill level, indicating they have mastered certain tasks associated with the maintenance and servicing of aircraft.

In addition to manpower considerations, an airfield's maintenance capability is influenced by the availability of maintenance equipment (Air Force Doctrine Document 2-6.3, 1999:34). Categories of maintenance-related equipment include Aerospace Ground Equipment (AGE), aircraft spares, and specialized support equipment. AGE, both powered and unpowered, supports maintenance and ground aircraft operations. Typical AGE items include ground power units, liquid-oxygen and liquid-nitrogen servicing carts, service stands, and oil carts.

Aircraft spares are parts needed to facilitate repair of the aircraft. The type and quantity of spares maintained at a particular location should be compatible with the airfield's maintenance concept (Air Force Doctrine Document 2-6.3, 1999:35). Minor en route locations, for instance, might typically store parts that would cause an aircraft to become non-mission capable.

The availability of unique support equipment can also influence an airfield's ability to service aircraft. Examples of specialized support equipment include snow removal equipment and special tools and test equipment. Distinctive characteristics of the airfield dictate the support equipment requirements for a particular location.

Aircraft ground servicing times are influenced by the maintenance capability present at a particular location. The availability of maintenance manpower and

equipment determines the types of tasks that can be accomplished, as well as the amount of time needed to complete servicing.

***Material Handling Equipment.***

MHE includes all ground equipment required to load and unload cargo and personnel onto military and commercial aircraft.  This equipment typically includes cargo loaders, buses, and forklifts.  The foundation of military cargo handling is the 463L System that employs 463L pallets and nets.  By developing a pallet that is compatible with a variety of cargo aircraft, load and unload ground service times are reduced (Anaya, 2001:16).  The time needed to complete cargo operations is therefore dependent on the availability and capacity of cargo loaders to service aircraft.   The basic types of cargo loaders include the 25,000-pound (25K) capacity loader, the 40K loader, the Wide Body Elevator Loader (WBEL), the Next Generation Small Loader (NGSL), and the Tunner 60K loader.  Table 1 below summarizes the pallet capacity of each loader, and notes whether the equipment is capable of servicing high-reach aircraft.

**Table 1.  Cargo Loader Characteristics (Anaya, 2001:20)**

| Item | Pallet Capacity | Reach Commercial Wide Body |
|---|---|---|
| 10K Forklift | 1 | No |
| 25K Loader | 3 | No |
| Next Generation Small Loader | 3 | Yes |
| 40K Loader | 5 | No |
| 60K Loader | 6 | Yes |
| Wide Body Elevator Loader | 2 | Yes |

Many of the 25K loaders have exceeded their life expectancy and require intensive maintenance to remain operational. Additionally, the 25K loader's 13-foot maximum lifting height limits its ability to service wide-body commercial aircraft that require a reach of 18 feet (Anaya, 2001:2). WBELs address the reach limitation of the 25K loader by providing the capability to lift 2 pallets to the floor of high-reach aircraft. However, the WBEL is not capable of transporting cargo between the aircraft and cargo marshalling yard, and the equipment has grown increasingly difficult to maintain due to its age. The NGSL was developed to replace the functionality of both the 25K loader and the WBEL. The NGSL is a 25,000-pound capacity transporter capable of servicing all military transport and Civil Reserve Air Fleet cargo aircraft (Anaya, 2001:1). By reducing the amount of cargo handling necessary to service wide-body aircraft, the NGSL improves cargo load and unload times and reduces the mobility footprint during deployment operations. The Tunner 60K loader, a replacement for the aging 40K transporter, provides the capacity to move six pallets. Like the NGSL, the 60K loader is capable of servicing high-reach aircraft.

***Airfield Characteristics.***

An airfield's infrastructure and local business rules can impact the number of aircraft that can be serviced by a particular location. Physical constraints include runway lengths and widths, ramp dimensions, surface conditions, load bearing capacity, and availability of hot cargo space (Air Force Doctrine Document 2-6.3, 1999:33). These characteristics limit the number and types of aircraft that can simultaneously park at the airfield. Additional infrastructure considerations include airfield navigational aids, weather forecasting, airfield lighting, security, and flight planning support.

In addition to the infrastructure limitations of the airfield, local business rules may influence the rate at which aircraft are serviced. For example, varying levels of maintenance performed at en route locations influence aircraft ground service times. Airfield hours of operation, maintenance quiet hours and other local restrictions may limit the aircraft servicing capacity of a particular location.

***Petroleum, Oils, and Lubricants.***

Finally, an airfield's capacity is impacted by POL-related factors. Because refueling operations are often not performed concurrently with other servicing activities, the number of aircraft that can be simultaneously refueled and the associated fuel transfer rates can have a significant impact on overall ground servicing times. Specific factors that influence an airfield's refueling times include bulk storage capacity, fuel equipment type and condition, dispense rates, and bulk resupply methods (Air Force Doctrine Document 2-6.3, 1999:34).

Aircraft refueling is typically accomplished by truck or via a hydrant-fueling system. The R-11 is the most common refueling vehicle, capable of refueling aircraft at up to 600 gallons-per-minute (gpm). Although refueling trucks provide the greatest flexibility and mobility for fueling operations, their 6000 gallon fuel capacity can result in increased refueling times for heavy aircraft. When multiple trucks are needed, connect/disconnect times and travel times to fillstands for resupply increase overall refueling times.

Hydrant systems provide the benefit of uninterrupted fuel flow. The most common hydrant-fueling systems are the Type II, Pritchard, system and the Type III looping system (Stucker and Berg, 1998:23). The Type II system can service up to three

aircraft simultaneously at a maximum transfer rate of 600 gpm. The Type III hydrant system is typically capable of pumping up to 2,400 gpm into a hydrant loop, allowing concurrent refueling of four aircraft at a rate of 600 gpm. An airfield's hydrant-servicing capacity, therefore, is limited by the number of hydrants available, the number of outlets associated with each hydrant, and dispense rates supported by each hydrant.

## Chapter Summary

This chapter has examined the existing literature with respect to the study of aircraft availability and the impact of base support resources on the availability of mobility aircraft. The current air mobility system consists of a network of mobility bases, each possessing varying levels of aircraft servicing capability. Several traditional measures of aircraft availability were presented, and the term as used in this study was defined. Airfield capacity, or a location's ability to make aircraft available, was examined, and some of the previous methods for assessing the capacity of airfields were discussed. Lastly, the factors identified in the literature as being critical to airfield capacity—maintenance capability, MHE, airfield characteristics, and POL—were reviewed. The subsequent chapter describes the procedure used in this study to investigate the relationship between critical mobility airfield resources and aircraft availability.

# III. Methodology

## Chapter Overview

This chapter describes the procedures used in this study to investigate the relationship between base support factors and aircraft availability. The chapter begins by discussing several of the approaches that have previously been developed to study mobility operations. Next, a description of the simulation model used for this study, the Airfield Simulation Tool, is provided that highlights the relevant characteristics of the tool. The overall objective of this study is presented, followed by a description of the experimental design. Additionally, the data collection effort necessary to facilitate development of the models is presented. The chapter concludes by examining output analysis issues such as bias initialization and statistical analysis of results.

## Airfield Capacity Models

Previous airlift studies involving airfield capacity have resulted in the development of a variety of modeling approaches. The Airlift Flow Model (AFM, formerly called the Mobility Analysis Support System, or MASS) is a legacy simulation used by mobility analysts at AMC to model the behavior of the airlift system under varying conditions. The AFM simulates the movement of aircraft throughout the air mobility network. However, the AFM has been criticized for producing results that are too optimistic (Stucker and Berg, 1998:2). Critics claim the AFM overestimates the airlift fleet's cargo-carrying capacity due in part to the manner in which the model measures airfield capacity. Under the direction of AMC/XPY, an improved simulation model, the Air Mobility Operations Simulator (AMOS), has been developed to replace

the analytic capability of AFM. Upon completion of model verification and validation, AMOS will be used to provide insight into airlift and air refueling operations.

In 1994, the Mobility Division of the Directorate of Forces, Headquarters, U.S. Air Force and the Force Projection Directorate of the Secretary of Defense requested that RAND's National Defense Research Institute develop an approach for improving estimates of airfield capacity. In response to this request, RAND analysts Stucker and Berg (1998:2) created a mathematical model called the Airfield Capacity Estimator (ACE). As noted in equation (4), the ACE expresses an airfield's capacity as the number of aircraft assigned a particular mission that can be serviced in one day given the availability of key resources (Stucker and Berg, 1998:8). Although the ACE model considers more airfield servicing activities and resources than previous methods, limitations of the model have been documented. Notably, the model is primarily deterministic, incorporating few stochastic inputs. Given the degree of variation of aerial port operations, therefore, ACE may produce optimistic estimates of airfield capacity (Williams, 1999: 28).

**Airfield Simulation Tool**

Simulation is an appropriate tool for studying complex and variable systems such as mobility airfield operations. For the purpose of this study, simulation enables the study of interactions of critical factors within a complex system. Additionally, simulation outputs offer valuable insights into which system variables are most important and how variables interact (Banks and Carson, 1984:4). This study uses the Airfield Simulation Tool (formerly called the Base Resource and Capabilities Estimator (BRACE)), a discrete-event simulation tool used to determine an airfield's throughput

capacity and resource requirements. The AST model was developed by Dr. Travis Cusick at the Center for Optimization and Semantic Control, Washington University, St. Louis under the direction of the Studies and Analysis division, HQ AMC. AST models an aircraft arrival stream and simulates the progression of each aircraft through major ground activities leading to departure. Figure 2 outlines the sequential schedule of activities encountered by arriving aircraft.

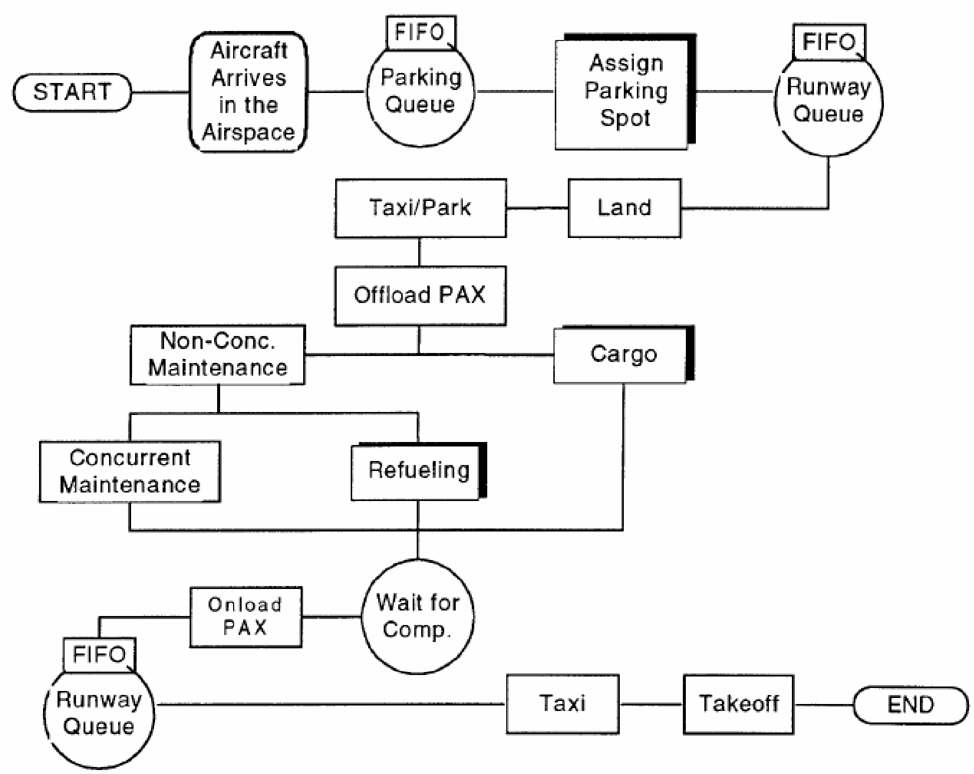



**Figure 2. Sequential Flow of AST Activities (Rodin, 2001:3)**

Each aircraft arrival places unique demands for resources on the airfield based on inherent attributes including: mission design series (i.e., C-17, C-5), mission profile, fuel requirement, component failure (called mission essential subsystem list (MESL) break),

and hot cargo (i.e., live munitions). When aircraft initially arrive in the airspace, a check is made to determine whether the airfield has ramp space available. If space is not open after a predetermined period of time, the aircraft diverts to an alternate location. Assuming parking space is available, the aircraft waits for an available runway, lands, and parks in an assigned spot. The aircraft then enters sequential queues for servicing from the airfield's resources based on the entity's attributes. Upon completion of servicing, the aircraft again waits for runway availability before departing the airfield (Cusick, 2002:4).

Validity of AST has been assessed through a variety of methods. The model exhibits high face validity as indicated by its wide acceptance and use within the air mobility community. Additionally, several recent airfield capacity studies (Mahan, Hankins and Koch, 2002: Jones, 2002: Mingee and Swartz, 2002) have verified AST model assumptions and outputs against real-world systems. AST version 2.6 (September 30, 2002), used in this study, incorporates improvements and enhancements made to the model since its initial development.

**Purpose**

A design of experiments using the AST simulation model was developed to describe the relationship between an airfield's resources and airfield throughput capacity. The output performance measure, or response variable, selected to represent airfield throughput was Total Aircraft Departures. In AST, Total Aircraft Departures represent the number of aircraft departing the airfield after completion of servicing activities. The number of aircraft departures serves as an indication of the airfield's ability to create available aircraft. The independent variables, or factors, included in the experimental

design were those model parameters that pertained directly to characteristics identified as being critical to airfield capacity—MHE, POL, maintenance manpower, and airfield characteristics (i.e., runways, ramp space).

A total of six experiments were conducted to investigate the relationship between base support resources and aircraft availability. Aerial port operations were modeled at Ramstein AB and NAS Sigonella, and three distinct aircraft arrival streams were used for each location. Each experiment consisted of 16 design points, yielding a total of 96 treatments for the study.

**Experimental Design**

The experimental design used for this study was a $2^k$ full factorial design, for which two levels (low and high) were chosen for each *k* factor. The simulation was then run at each of the $2^k$ possible factor-level combinations (called design points). As noted by Law and Kelton (1991:660), the $2^k$ factorial design provides an economical means of measuring interaction between important factors, allowing main effects and interactions to be assessed independently. As noted above, endogenous variables were aggregated into one of four categories, resulting in a $2^4$ factorial design consisting of 16 design points. A tabular form of the experiment is provided in the design matrix, Table 2 below. Low factor levels are designated by a minus sign, and high factors levels are denoted by a plus sign. No general prescription exists for how one should specify the levels, though the specification of reasonable values is necessary to ensure model outputs are meaningful and credible (Law and Kelton, 1991:660). For this study, low level factor values

**Table 2. Design Matrix for $2^4$ Factorial**

| Factor Combination (design point) | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Response |
|---|---|---|---|---|---|
| 1 | - | - | - | - | $R_1$ |
| 2 | + | - | - | - | $R_2$ |
| 3 | - | + | - | - | $R_3$ |
| 4 | + | + | - | - | $R_4$ |
| 5 | - | - | + | - | $R_5$ |
| 6 | + | - | + | - | $R_6$ |
| 7 | - | + | + | - | $R_7$ |
| 8 | + | + | + | - | $R_8$ |
| 9 | - | - | - | + | $R_9$ |
| 10 | + | - | - | + | $R_{10}$ |
| 11 | - | + | - | + | $R_{11}$ |
| 12 | + | + | - | + | $R_{12}$ |
| 13 | - | - | + | + | $R_{13}$ |
| 14 | + | - | + | + | $R_{14}$ |
| 15 | - | + | + | + | $R_{15}$ |
| 16 | + | + | + | + | $R_{16}$ |

represent baseline, empirical values obtained from source documents for each airfield. To obtain high level values, parameters were adjusted by 30% in a direction that should increase capacity of the parameter. For example, in a location where 10 R-11 fuel trucks are assigned, this value would be increased by 3 trucks resulting in a "high" level of 13 trucks for that particular parameter.

Validity of the procedure was considered to address the accuracy and generalizability of analysis results. As mentioned previously, validity of the AST model itself has been ascertained through its wide use and acceptance by mobility analysts. Because AST models just a single location, however, two separate airfield models were developed in order to enhance external validity. The locations selected for this study include Ramstein AB, a major en route location, and NAS Sigonella, a minor en route stop. Additionally, the analysis involved servicing of two different aircraft, C-17s and C-

5s. Separate trials were conducted to model C-17 only arrivals, C-5 only arrivals, and a 50/50 mix of C-17/C-5 arrivals. These aircraft were chosen because they represent the current backbone of strategic airlift capability, and because each MDS places unique demands on an airfield due to its distinctive attributes. Validity of the models was assessed by comparing baseline model outputs to empirical aircraft departure data obtained from HQ AMC/LGMQA. It should be noted, however, that this design of experiments represents a "fixed effects" model because factor levels were not randomly assigned, but were purposefully selected. As such, results of the analysis may not be generalized beyond the particular values selected for the experiment (Kachigan, 1991:212).

***Data Collection.***

In order for a simulation model to produce credible results, input data must be representative of the system. Location specific information was collected from a variety of source documents. Airfield characteristics were grouped into four fields: airfield parking, cargo operations, fuels, and maintenance breakdown and repair distribution data. Specific parameters and values are identified in Appendix A (Ramstein AB) and Appendix B (NAS Sigonella). The source documents used to collect the data include the following:

Core Automated Maintenance System for Mobility (CAMS FM-G081)- The G081 Maintenance Information System is the central data source for all unclassified maintenance for mobility tanker and airlift aircraft. Maintenance break rates and repair time distributions for a one-year period starting November 2001 were obtained for Ramstein AB and NAS Sigonella via the G081 break-fix batch report. Additionally,

aircraft arrival information for each location was obtained from G081 for the same period.

Base Support Plans (BSPs)- Per Air Force Instruction 10-404 (2001:7), installation commanders are responsible for developing and maintaining BSPs for their respective locations. Part 1 of the base support plan site plan identifies resources and capabilities of a location by functional area.

Logistician's Contingency Assessment Tools (LOGCAT)- The LOGCAT is a suite of standard systems tools that enables automated, employment-driven, base support planning. LOGCAT component, Survey Tool for Employment Planning (STEP), partially automates the overall base support planning process and standardizes expeditionary site planning products via a sophisticated, multimedia tool for the collection of base/site data. The Employment Knowledge Base database stores all STEP produced BSP information.

***Output Analysis.***

Because aerial port activities are continuous with no clearly defined ending point, the simulation modeling these activities is considered a non-terminating system. To draw accurate conclusions from the results of non-terminating simulations, the analyst must include for analysis only that data collected while the system is in a steady-state. During the transient phase of the simulation, model output does not represent true system performance because of the residual effect of initial conditions. In this study, the transient effects of initialization bias are of particular concern because the AST simulation starts with zero aircraft entities present in the system. Welsh's graphical procedure was used to identify and truncate the transient phase of the simulation models used in this study. Welsh's technique involves determining a warmup period such that

the transient mean curve of the response variable flattens out at the steady state mean (Law and Kelton, 1991:545). The procedure was employed for both Ramstein AB and NAS Sigonella . Total Aircraft Departures per day were computed for each scenario, and mean departures per day were plotted. A moving average of the data was generated using a window of 2 days resulting in a reasonably smooth plot from which an appropriate warmup period could be determined. Rather than use this warmup period for the experiment, this value was increased by 100% to account for longer transient periods that might occur in other treatments involved in the design. The AST provides the capability to reset output statistics after a given number of days, thereby removing initialization bias from results. To determine the length of each simulation, a heuristic approach was used that involves modeling steady-state behavior for a period equal to 10 times the amount of truncated data.

***Number of Replications.***

Although an intended purpose of simulation is to estimate true system performance measures through statistical analysis of model outputs, the assumption of an independent, identically distributed random variable necessary to satisfy classical statistical techniques is not directly satisfied when a single run is used. For example, the value of $T_i$ (where T represents the total aircraft departures on day $i$) is dependent on the state of the system on day $i - 1$. This problem of autocorrelation is mitigated by conducting multiple replications of the model. For this study, the number of replications was calculated based on a desired level of accuracy (precision ($\varepsilon$) = 10 departures, 90% confidence) with regard to the output performance measure Total Aircraft Departures.

Sample variance ($S_0$) associated with the response variable was determined by conducting 5 initial replications (pilot runs) for each of the 96 design points. The number of replications (R) is the smallest integer satisfying

$$R \geq \left( \frac{t_{\alpha/2,R-1} S_0}{\varepsilon} \right)^2 \qquad (5)$$

The "worst case" variance was identified, and this value was used in equation 5 so that all design points in the study would contain the same number of replications.

Analysis of variance (ANOVA) techniques were employed to detect difference of means between treatment groups. The test statistic is defined as $F = MST / MSE$ where MST represents the Mean Square for Treatments and MSE equals the Mean Square for Error. For F-test results to be valid, the following assumptions must be satisfied (Benson, McClave and Sincich, 2001:825):

1. The probability distributions of the response variables associated with each treatment must all be normal and possess equal variance.
2. The samples of experimental units selected for the treatments must be random and independent.

Tests for normality and equal variance are included in the subsequent chapter. The second assumption above was satisfied by the completely randomized design and multiple replications involved in the experiment. The null hypothesis for each of the six experiments was that treatments means were equal. When a difference between means was detected, resulting in a rejection of the null hypothesis, the full model effect tests were analyzed to facilitate screening of statistically significant factors. Using an iterative

approach, a reduced model was developed for each of the six experiments that enabled the identification of important factors. Conclusions were drawn based on the results of these reduced models.

## Chapter Summary

The purpose of this chapter has been to describe the procedures used in this study to investigate the relationship between base support factors and airfield throughput. The study makes use of the Airfield Simulation Tool to model servicing activities at Ramstein AB and NAS Sigonella. A $2^4$ full factorial design was described that investigates the main effects and interactions between critical input factors and the response variable, Total Aircraft Departures. The subsequent chapter discusses model results, and analysis of the data collected during the experiment.

# IV. Results and Analysis

## Chapter Overview

The purpose of this chapter is to present the results and statistical analyses performed for each of the six experiments used to investigate the relationship between critical base support factors and aircraft availability. A description of the simulation model parameters is presented that includes aircraft arrival characteristics and general model assumptions. The calculation for the required number of replications for each treatment is presented, followed by the graphical identification of initialization bias associated with both the Ramstein AB and NAS Sigonella models. Statistical analysis of the simulation results for each of the six designs is described. This analysis facilitates the identification of base support factors having the greatest practical significance in terms of airfield throughput. The chapter begins with a discussion of the experimental design.

## Experimental Design

As described in Chapter 3, the relationship between base resources and airfield throughput was addressed by conducting six separate simulation experiments, each involving 16 design points. Using a $2^4$ full factorial design, the analysis assessed the impact of four categories of base support resources on airfield throughput. These categories include maintenance capability, cargo resources, airfield characteristics, and POL resources. Aerial port operations were modeled at Ramstein AB and NAS Sigonella, and three distinct aircraft arrival streams were used for each location. Specific details regarding aircraft configurations for each of the six experiments are displayed in

Table 3. Aircraft payloads arriving at Ramstein AB were based on planning factors identified in AFPAM 10-1403. These planning factors were calculated based on Desert Storm/Shield averages (Department of the Air Force, 1998: 13).

**Table 3. Summary of Model Aircraft Arrival Profiles**

| Model | MDS | % of Arrivals | Cargo | Reason for Stop | Fuel | Narrow Body Equivalence |
|---|---|---|---|---|---|---|
| Ramstein C-17 only | C-17 | 50% | 39.6 s/t | Offload | 13,450 gal | 1.13 |
| | C-17 | 50% | 30 s/t | Onload | 6,725 gal | 1 |
| Ramstein C-5 Only | C-5 | 50% | 61.3 s/t | Offload | 17,500 gal | 2 |
| | C-5 | 50% | 20 s/t | Onload | 8,750 gal | 2 |
| Ramstein C-5/C-17 Mix | C-5 | 25% | 61.3 s/t | Offload | 17,500 gal | 2 |
| | C-5 | 25% | 20 s/t | Onload | 8,750 gal | 2 |
| | C-17 | 25% | 39.6 s/t | Offload | 13,450 gal | 1.13 |
| | C-17 | 25% | 30 s/t | Onload | 6,725 gal | 1 |
| Sigonella C-17 only | C-17 | 50% | 19 s/t | Onload | 13,450 gal | 1.13 |
| | C-17 | 50% | N/A | Enroute | 6,725 gal | 1 |
| Sigonella C-5 Only | C-5 | 50% | 30 s/t | Onload | 17,500 gal | 2 |
| | C-5 | 50% | N/A | Enroute | 8,750 gal | 2 |
| Sigonella C-5/C-17 Mix | C-5 | 25% | 30 s/t | Onload | 17500 gal | 2 |
| | C-5 | 25% | N/A | En Route | 8,750 gal | 2 |
| | C-17 | 25% | 19 s/t | Onload | 13,450 gal | 1.13 |
| | C-17 | 25% | N/A | Enroute | 6,725 gal | 1 |

The offload requirement for C-17 aircraft was revised downward to 39.6 short tons (s/t) from a 45 s/t planning factor to accommodate the average pallet weight modeled (2.2 s/t per pallet) and the maximum number of pallets positions on the C-17 aircraft. Cargo servicing was not necessary for aircraft arriving at NAS Sigonella for en route, gas-and-go servicing only. Fuel requirements for arriving aircraft were based on MDS-specific fuel burn rate planning factors identified in AFPAM 10-1403.

Narrow-body equivalence describes the number of narrow-body parking spots needed to accommodate a particular MDS. These values were obtained from AFPAM 10-1403. According to this guidance, the C-17 may only park in a narrow-body spot

when wing walkers are available. For this reason, 50% of C-17 arrivals were modeled as requiring wide-body parking spots.

### Modeling Assumptions

The following analysis assumptions apply to all six experiments conducted during this study:

1. For the purpose of this study, movement of cargo was simulated between aircraft and the loading docks only. Although AST provides the capability to simulate cargo movement beyond the dock, this capability was not considered constraining to the airfield's servicing of aircraft.
2. Manpower was assumed to be adequate to perform activities and operate critical resources modeled in each of the six experiments.
3. All locations provide 24/7 aerial port operations.
4. Concurrent maintenance activities are not permitted. That is, aircraft maintenance and servicing is not permitted while either cargo operations or refueling operations are taking place.
5. Bulk (palletized) cargo was simulated. Passengers and unpalletized cargo were not modeled in this study.

### Number of Replications and Initialization Bias

As discussed in Chapter 3, the number of replications conducted for each design point was calculated by determining the highest sample variance from among the pilot runs for all 96 treatments. The maximum observed standard error from among the 96 design points was 25.67. Using a level of significance of $\alpha = 0.10$ and precision $\varepsilon = 10$ departures resulted in a requirement for at least 19.702 replications. Therefore, 20

replications were run for all design points within each of the six experiments. As discovered in the model results below, parameter power obtained via 20 replications proved sufficient to attain statistically significant test results.

The identification of the transient periods associated with both the Ramstein AB and NAS Sigonella scenarios was determined by conducting 30 replications of each baseline model for a period of 30 days. The mean number of aircraft departures per day was calculated and plotted. Using Welsh's graphical procedure as described in Chapter 3, a smoothed trend was plotted for the response variable based on a window of two days. Figure 3 shows the graphical interpretation of initialization bias for the Ramstein AB baseline model. The transient period is identified as the point at which the trend line

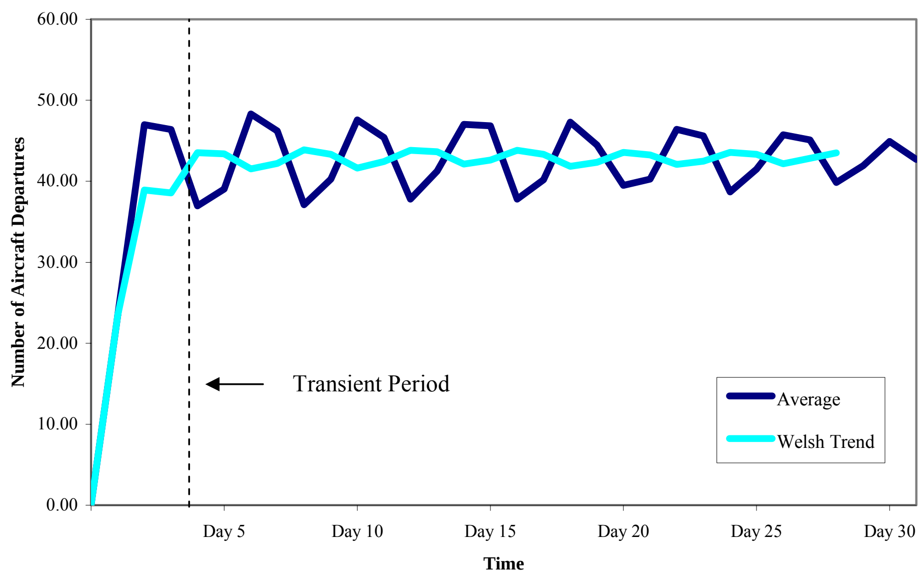



**Figure 3. Initialization Bias- Ramstein AB Model**

approximates the steady-state mean. As illustrated in Figure 3, this period is approximately four days in the Ramstein model. This value was doubled to account for potential variations among treatments, resulting in a warm-up period of eight days for

each of the Ramstein AB design points. Statistics for each of the Ramstein AB experiments were reset of eight days. Figure 4 displays the Welsh plot for the NAS Sigonella baseline model. In this case, the simulation appears to reach a steady state after approximately two days. Therefore, statistics associated with the Sigonella design points were reset after four days.

## Analysis of Ramstein AB Models

The Ramstein AB models were developed to investigate the impact of base support resources on throughput of an airfield possessing major en route capability. Model assumptions unique to Ramstein are provided in Appendix A, along with the base support factors modeled and their respective levels. The subsequent discussion details the results and analysis for the three scenarios involving Ramstein AB.

### *C-5/C-17 Ramstein Model.*

The first experiment examined aerial port operations at Ramstein AB given an aircraft arrival mix of C-5 and C-17 cargo aircraft. As discussed in Chapter 3, the experiment began with a full factorial analysis of the main effects and interactions using an ANOVA procedure. After conducting 20 replications of the simulation for each design point, the results were imported into the SAS Institute's JMP statistical software package (release 5.0.1) for analysis. Initially, an analysis of the error residuals was performed to ensure statistical assumptions were satisfied. As illustrated in Figure 5, the normal quantile plot and associated frequency distribution confirm the assumption of normality. To verify that variance was constant among treatment means, error residuals

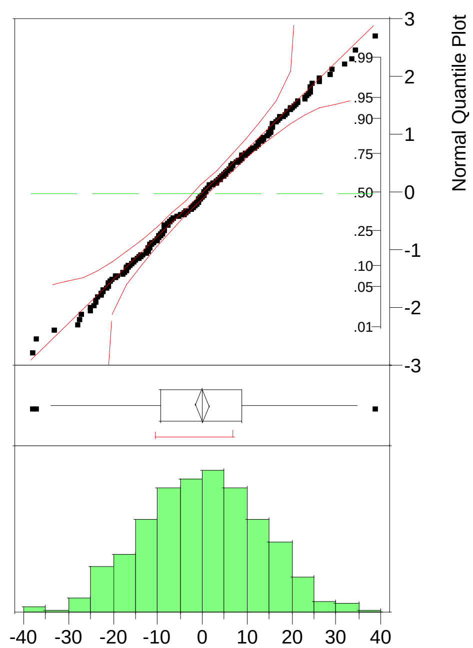



**Figure 5. Normal Quantile Plot of Error Residuals- Ramstein**

were plotted against predicted values. As shown in Figure 6, residual variance appears constant. The final assumption of random and independent samples was satisfied by the randomized design of the simulation. Having confirmed the statistical assumptions, an ANOVA analysis of the full model was conducted.

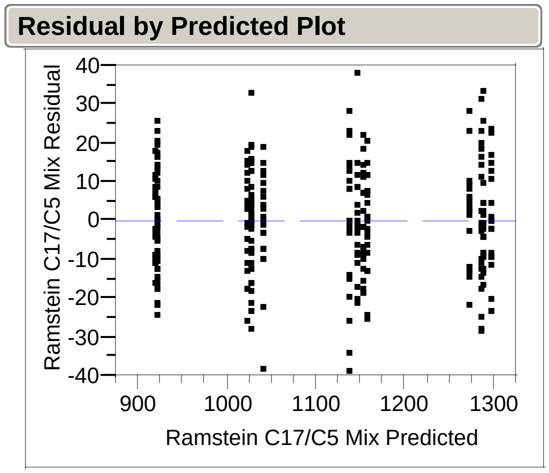



**Figure 6. Plot of Residual Errors against Predicted Values- Ramstein**

Using JMP's Fit Model capability, the impact of all main effects and interaction effects on the response variable, Total Aircraft Departures, was assessed using the standard least squares personality. The analysis used a p-value alpha of 0.05. Numerator degrees of freedom for the F statistic were determined by subtracting one from the number of treatments, yielding 15 between treatments degrees of freedom. Denominator degrees of freedom were found by subtracting the number of treatments from the total number of replications. Therefore, using 304 denominator degrees of freedom for within treatment variance yielded a critical F statistic value of 1.699. An observed F-ratio value exceeding this critical value serves as an indication that a statistically significant difference exists between treatment means, thereby resulting in a rejection of the null hypothesis that all treatment means are equal. A summary of the full model ANOVA results is displayed in Table 4. The observed F-ratio value of 2129.481 indicates that a

**Table 4. ANOVA Summary- Ramstein C-5/C-17 Models**

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 15 | 5939527.6 | 395969 | 2129.481 |
| Error | 304 | 56527.6 | 186 | Prob > F |
| C. Total | 319 | 5996055.2 | | <.0001 |

statistically significant difference exists between treatment means in this experiment. The coefficient of determination, or R-squared value, represents the proportion of variance accounted for by fitting the mean response values to their respective factor levels. Defined as the ratio of the sum of squares model variance to sum of squares total variance, the R-square value obtained in this analysis equals 5939527.6 divided by 5996055.2, or 0.990573. A high coefficient of determination serves as evidence that the fit model may reliably be used to screen important factors.

The cube plot in Figure 7 provides a graphical representation of the mean aircraft departures over a 30-day period for each of the 16 treatments. A visual inspection of cube plot reveals that an average of 921.85 aircraft departures occurred when all factors were set to their respective low levels. Additionally, mean total departures appear to increase significantly when POL resources or airfield characteristics are at high levels. To ascertain the statistical significance of this observation, the effect tests were analyzed. Table 5 contains the effect tests for the full factorial model. Analysis of the effect tests

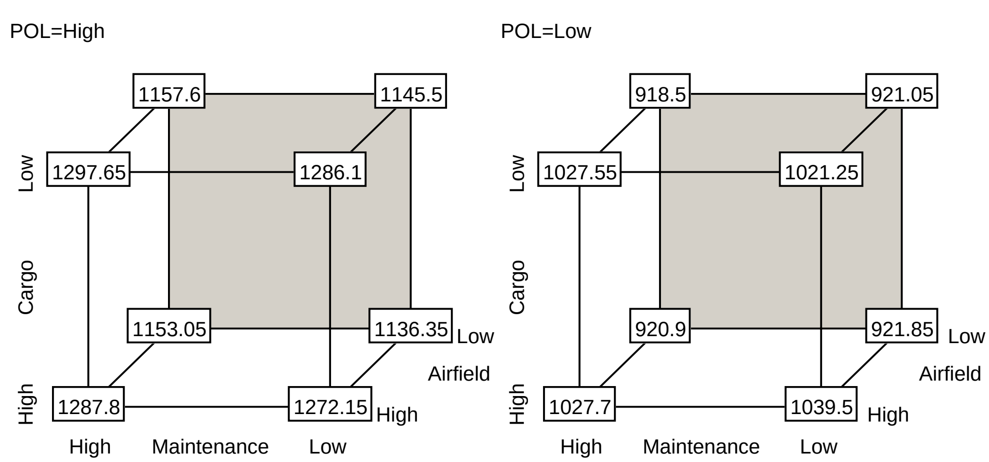



**Figure 7. Cube Plot of Treatment Means- Ramstein C-5/C-17 Models**

reveals certain interaction effects are not statistically significant. To obtain a model with which to study important factor impacts, a reduced model was developed by removing effects exceeding a level of significance of 0.05. The remaining effects consisted primarily of main effects and second order interaction effects involving POL. Statistical

**Table 5. Effect Tests for Ramstein C-5/C-17 Models**

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Maintenance | 1 | 1 | 2761.3 | 14.8497 | 0.0001 |
| Cargo | 1 | 1 | 316.0 | 1.6995 | 0.1933 |
| Airfield | 1 | 1 | 1212535.0 | 6520.897 | <.0001 |
| POL | 1 | 1 | 4694320.5 | 25245.6 | <.0001 |
| Maintenance*Cargo | 1 | 1 | 76.1 | 0.4090 | 0.5230 |
| Maintenance*Airfield | 1 | 1 | 16.2 | 0.0871 | 0.7681 |
| Cargo*Airfield | 1 | 1 | 32.5 | 0.1748 | 0.6761 |
| Maintenance*POL | 1 | 1 | 5281.3 | 28.4021 | <.0001 |
| Cargo*POL | 1 | 1 | 4366.0 | 23.4800 | <.0001 |
| Airfield*POL | 1 | 1 | 17257.8 | 92.8109 | <.0001 |
| Maintenance*Cargo*Airfield | 1 | 1 | 510.1 | 2.7430 | 0.0987 |
| Maintenance*Cargo*POL | 1 | 1 | 793.8 | 4.2690 | 0.0397 |
| Maintenance*Airfield*POL | 1 | 1 | 0.2 | 0.0011 | 0.9739 |
| Cargo*Airfield*POL | 1 | 1 | 800.1 | 4.3029 | 0.0389 |
| Maintenance*Cargo*Airfield*POL | 1 | 1 | 460.8 | 2.4781 | 0.1165 |

assumptions were again verified for the reduced model. The R-square value of this reduced model was 0.989343, which indicated much of the variance was still explained despite the removal of screened effects. To further assess the relationship between effects, a Pareto plot of the parameter estimates generated by JMP was developed to provide a graphical representation of the effect sizes. The Pareto plot for this scenario is shown in Figure 8. The size of the effect is portrayed by length of the associated bar plot. Analysis of Figure 8, therefore, indicates that changes in POL capability had the greatest

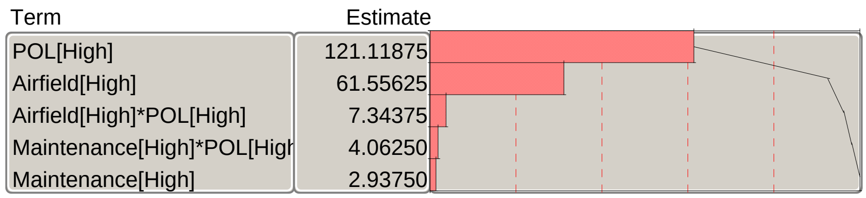



**Figure 8. Pareto Plot of Parameter Estimates- Ramstein C-5/C-17 Models**

impact on airfield throughput, followed by increases in airfield parking. Although the remaining effects were statistically significant, the magnitude of the respective parameter estimates in the Pareto plot suggests the practical significance of these factors is minimal as compared to POL and airfield main effects.

***C-17 Only Ramstein Model.***

The second experiment investigated the relationship between Ramstein-related base support factors and throughput of C-17 cargo aircraft. Again, 20 replications of the simulation were conducted for each of the 16 design points. Residual errors were evaluated to ensure the assumptions of normality and constant variance were not violated. A summary of the full model ANOVA results is provided in Table 6. The observed F-ratio and associated p-value suggest that the null hypothesis should be rejected, which

**Table 6. ANOVA Summary- Ramstein C-17 Models**

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 15 | 9418341.4 | 627889 | 2988.962 |
| Error | 304 | 63861.1 | 210 | Prob > F |
| C. Total | 319 | 9482202.5 | | 0.0000 |

indicates the presence of a statistical difference between treatment means. The model exhibited an R-square value of 0.993265, which implies that the variance between treatment means is much greater than the variance attributable to random sampling error. The analysis continued with an inspection of the treatment means associated with each design point.

The cube plot in Figure 9 identifies the mean number of C-17 departures for this experiment. As discovered in the previous scenario in which a mix of C-17 and C-5

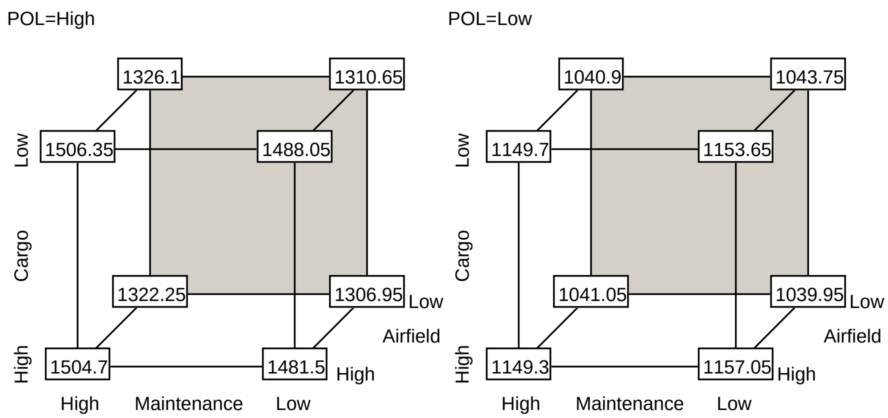



**Figure 9. Cube Plot Treatment Means- Ramstein C-17 Models**

aircraft were modeled, the average number of departures over a 30-day period appears to increase significantly when POL or airfield factors are set to a high level. The effect tests were examined to determine which factors were statistically significant. The effects identified as being statistically significant include all main effects with the exception of cargo, and second order interaction effects POL*maintenance and POL*airfield characteristics. A reduced model was developed using these screened factors to highlight the size of the important effects. Statistical assumptions related to the reduced model were verified and the coefficient of determination was checked to ensure removal of

screened effects had not significantly decreased the power of the model. Figure 10 depicts the Pareto plot for this experiment. As denoted by the size of the bar

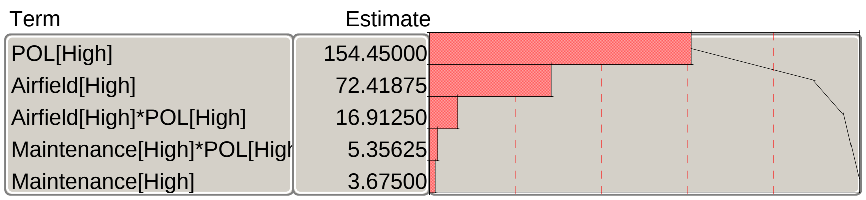



**Figure 10. Pareto Plot of Parameter Estimates- Ramstein C-17 Models**

plots, POL and airfield parking were the most significant effects. Similar to the previous scenario, the remaining main effects and interactions included in the reduced model, while statistically significant, appear to be of much less practical significance than POL and airfield main effects.

***C-5 Only Ramstein Model.***

The final Ramstein AB scenario examined the impact of varying levels of base support resources on the throughput of C-5 aircraft. After conducting 20 replications of each of the 16 factor/level combinations, the data were imported into JMP for development of the full factorial least squares model. Statistical assumptions were again verified through analysis of the residual errors. The least squares approach was again used to test the null hypothesis. A summary of the whole-model ANOVA results is displayed in Table 7.

**Table 7. ANOVA Summary- Ramstein C-5 Models**

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 15 | 3455580.9 | 230372 | 983.0953 |
| Error | 304 | 71237.3 | 234 | Prob > F |
| C. Total | 319 | 3526818.2 | | <.0001 |

The observed F-ratio confirms the alternate hypothesis that a difference between treatment means exists. The R-square value associated with this model was 0.979801, which suggests that effects tests may reliably be used to identify significant factors in this particular model. Mean departures for each of the 16 design points are summarized via cube plots in Figure 11. As compared to the previous two experiments in which the

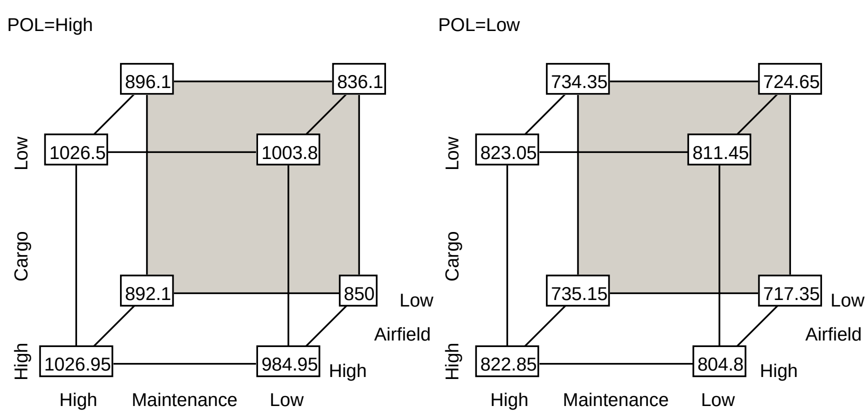



Figure 11. Cube Plot Treatment Means- Ramstein C-5 Models

arrivals of a mix of C-17/C-5 and C-17 only were modeled, average airfield throughput appears lowest when C-5 only arrivals are involved. The table of effect tests for this experiment was analyzed to determine those factors having a significant impact on the mean number of departures. The effects tests are presented in Table 8. Using an alpha

**Table 8. Effect Tests for Ramstein C-5 Models**

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Maintenance | 1 | 1 | 62692.0 | 267.5334 | <.0001 |
| Cargo | 1 | 1 | 596.8 | 2.5467 | 0.1116 |
| Airfield | 1 | 1 | [illegible] | [illegible] | [illegible] |
| Maintenance*Airfield | 1 | 1 | 1553.2 | 6.6282 | 0.0105 |
| Cargo*Airfield | 1 | 1 | 1026.0 | 4.3785 | 0.0372 |
| Maintenance*POL | 1 | 1 | 15028.9 | 64.1347 | <.0001 |
| Cargo*POL | 1 | 1 | 29.4 | 0.1255 | 0.7234 |
| Airfield*POL | 1 | 1 | 58997.0 | 251.7650 | <.0001 |
| Maintenance*Cargo*Airfield | 1 | 1 | 1579.8 | 6.7415 | 0.0099 |
| Maintenance*Cargo*POL | 1 | 1 | 216.2 | 0.9224 | 0.3376 |
| Maintenance*Airfield*POL | 1 | 1 | 1955.3 | 8.3439 | 0.0041 |
| Cargo*Airfield*POL | 1 | 1 | 976.5 | 4.1672 | 0.0421 |

criterion of 0.05, nearly all main effects and interaction effects appear to be statistically significant in this scenario with the exception of several effects involving cargo. A reduced model was developed that included each of the statistically significant effects identified above. A check of the summary of fit indicated that the new reduced model maintained a high coefficient of determination (R-square = 0.977922). A Pareto plot of the parameter estimates, shown in Figure 12, was analyzed to assess the practical significance of the effects in the reduced model. As discovered in previous Ramstein models, POL and airfield parking effects represent the greatest contributors to reduced model. Although the disparity between these factors and the other effects appears to have diminished when a fleet consisting of C-5 aircraft only is modeled, the Pareto plot again confirms that concern for the remaining effects is negligible compared to the impact of enhanced POL capability and aircraft parking.

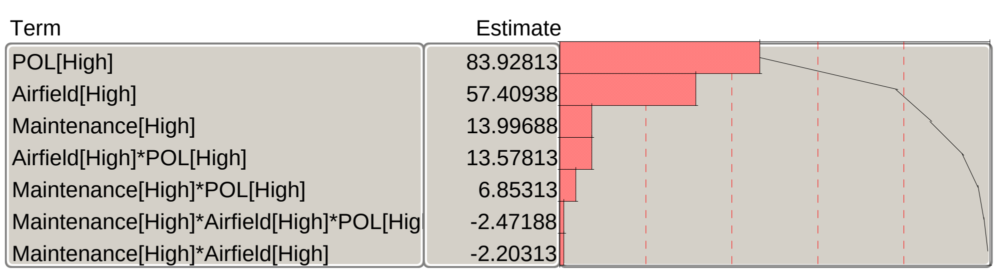



**Figure 12. Pareto Plot of Parameter Estimates- Ramstein C-5 Models**

**Analysis of NAS Sigonella Models**

The NAS Sigonella models were developed to investigate the impact of varying base support resources on throughput of an airfield possessing minor en route capability. Model assumptions unique to Sigonella, including maintenance break rate and repair levels and base support factors/levels, are provided in Appendix B. The following discussion examines each of the three Sigonella models independently.

***C-5/C-17 Mix Sigonella Model.***

The first model developed using Sigonella resources involved the arrival of a mix of C-5 and C-17 aircraft. Initially, 20 replications of the simulation were conducted for each of the 16 design points. The resulting vector of outputs representing the total number of aircraft departures for each treatment was imported into JMP for statistical analysis. The analysis began with a check of the statistical assumptions by examining the residual errors associated with the fitted model. The normal quantile plot and associated frequency distribution of the residuals is presented in Figure 13. The assumption of normality is confirmed by the general mound-shape of the distribution and the straight-line fit of the residual plots. To verify constant variance among treatment groups, the residuals were plotted against predicted values as shown in Figure 14. An inspection of this plot suggests that the assumption of constant variance is satisfied.

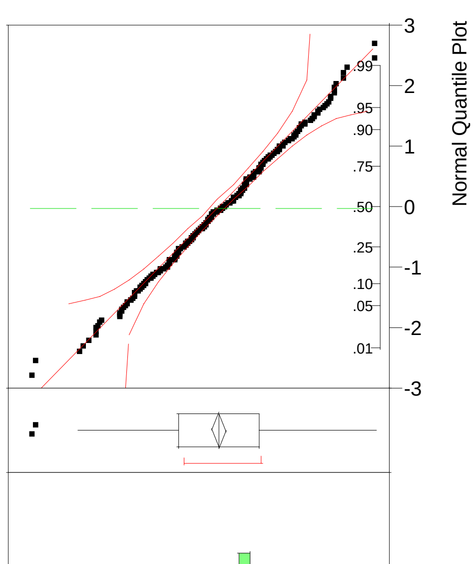
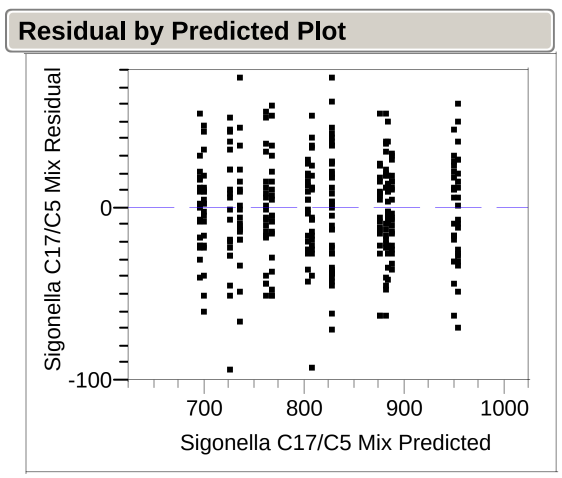


**Figure 13. Normal Quantile Plot of Error Residuals- Sigonella**

**Figure 14. Plot of Residual Errors against Predicted Values- Sigonella**

After verif[...]as assessed to determine the amount of variance explained by the full model. The observed coefficient of determination was 0.881134. While this R-square value is smaller than the observed




power of the Ramstein AB scenarios, this level was considered adequate for determining the size of important model effects in this model. Next, the full model ANOVA results were inspected to determine whether a statistically significant difference between

treatment means was present. The observed value of the F statistic was 150.23 as shown in the ANOVA summary in Table 9. Because this value clearly exceeds the critical F-

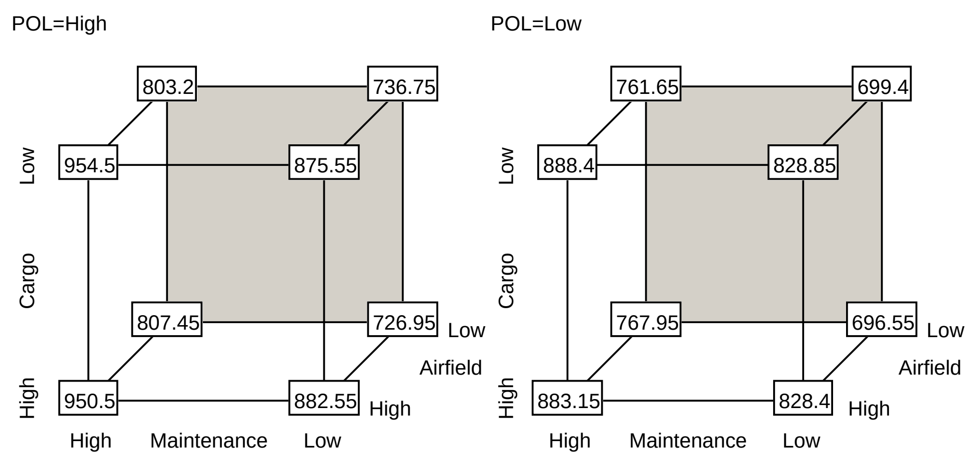



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**Figure 15. Cube Plot of Treatment Means- Sigonella C-5/C-17 Models**

to have a significant impact on airfield throughput. An examination of the effect tests was conducted to confirm the size of the important factors. Using the effect tests in

**Table 9. ANOVA Summary- Sigonella C-5/C-17 Models**

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 15 | 2056225.3 | 137082 | 150.2337 |
| Error | 304 | 277386.7 | 912 | Prob > F |
| C. Total | 319 | 2333612.0 | | <.0001 |

Table 10. … in a
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and POL … ced
model wa … ent.
Screening … the
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maintenance, and POL main effects.  The interaction effect POL*airfield parking, while statistically significant, does not appear to add practical significance to the model.

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Maintenance | 1 | 1 | 366934.1 | 402.1388 | <.0001 |
| Cargo | 1 | 1 | 28.8 | 0.0316 | 0.8591 |
| Airfield | 1 | 1 | 1490580.0 | 1633.591 | <.0001 |
| POL | 1 | 1 | 183457.0 | 201.0584 | <.0001 |
| Maintenance*Cargo | 1 | 1 | 68.5 | 0.0750 | 0.7844 |
| Maintenance*Airfield | 1 | 1 | 470.5 | 0.5156 | 0.4733 |
| Cargo*Airfield | 1 | 1 | 0.5 | 0.0005 | 0.9823 |
| Maintenance*POL | 1 | 1 | 2633.5 | 2.8862 | 0.0904 |
| Cargo*POL | 1 | 1 | 0.1 | 0.0001 | 0.9911 |
| Airfield*POL | 1 | 1 | 9137.8 | 10.0145 | 0.0017 |
| Maintenance*Cargo*Airfield | 1 | 1 | 1901.3 | 2.0837 | 0.1499 |
| Maintenance*Cargo*POL | 1 | 1 | 2.1 | 0.0023 | 0.9617 |
| Maintenance*Airfield*POL | 1 | 1 | 465.6 | 0.5103 | 0.4756 |
| Cargo*Airfield*POL | 1 | 1 | 391.6 | 0.4292 | 0.5129 |
| Maintenance*Cargo*Airfield*POL | 1 | 1 | 154.0 | 0.1688 | 0.6815 |

**Table 10.  Effect Tests for Sigonella C-5/C-17 Models**

| Term | Estimate |
|---|---|
| Airfield[High] | 68.250000 |
| Maintenance[High] | 33.862500 |
| POL[High] | 23.943750 |
| Airfield[High]*POL[High | 5.343750 |

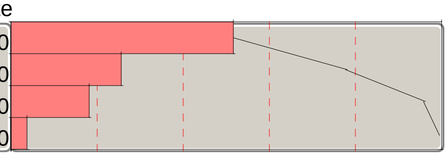

**Figure 16.  Pareto Plot of Parameter Estimates- Sigonella C-5/C-17 Models**

***C-17 Only Sigonella Model.***

The second experiment involving Sigonella aerial port operations examined the influence of base support resources given an arrival fleet of C-17 aircraft.  After completing the 320 design matrix replications, an analysis of variance procedure was conducted using the least squares personality.  Statistical assumptions for normality and constant variance were verified as described in the previous experiment.  The observed R-square value of 0.897579 for the full model was considered sufficient to facilitate the identification of important factors in this experiment.  As indicated by the full model ANOVA results in Table 11, the observed F-ratio value of 177.61 and resulting p-value serve as evidence that a statistically significant difference exists between treatment means.  The null

**Table 11.  ANOVA Summary- Sigonella C-17 Models**

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 15 | 2288827.4 | 152588 | 177.6093 |
| Error | 304 | 261173.8 | 859 | Prob > F |
| C. Total | 319 | 2550001.2 | | <.0001 |

hypothesis that all means are equal, therefore, is rejected.  Cube plots of the treatment means are shown in Figure 17.  When all factors are set to “low” levels, the average throughput of the airfield is 909.6 departures.  With the exception of cargo resources, all main effects appear to have a significant impact on the number of departures generated.

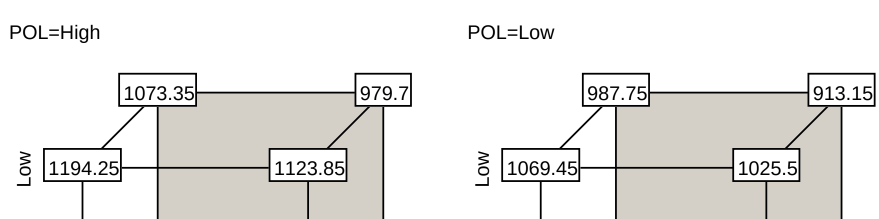

**Figure 17.  Cube Plot of Treatment Means- Sigonella C-17 Models**

a reduced model.  Table 12 identifies each of the 16 treatment effects and their respective p-values.  The effects selected for the reduced model, based on a desired alpha of 0.05, include maintenance, airfield, and POL main effects, as well as maintenance*POL and

**Table 12.  Effect Tests for Sigonella C-17 Models**

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Maintenance | 1 | 1 | 390321.8 | 454.3252 | <.0001 |
| Cargo | 1 | 1 | 300.3 | 0.3496 | 0.5548 |
| Airfield | 1 | 1 | 1125276.8 | 1309.795 | <.0001 |
| POL | 1 | 1 | 720291.0 | 838.4014 | <.0001 |
| Maintenance*Cargo | 1 | 1 | 51.2 | 0.0596 | 0.8073 |
| Maintenance*Airfield | 1 | 1 | 11785.5 | 13.7181 | 0.0003 |
| Cargo*Airfield | 1 | 1 | 1170.5 | 1.3624 | 0.2440 |
| Maintenance*POL | 1 | 1 | 9245.0 | 10.7610 | 0.0012 |
| Cargo*POL | 1 | 1 | 90.3 | 0.1051 | 0.7460 |
| Airfield*POL | 1 | 1 | 29722.1 | 34.5957 | <.0001 |
| Maintenance*Cargo*Airfield | 1 | 1 | 143.1 | 0.1666 | 0.6835 |
| Maintenance*Cargo*POL | 1 | 1 | 31.3 | 0.0364 | 0.8489 |
| Maintenance*Airfield*POL | 1 | 1 | 208.0 | 0.2421 | 0.6230 |
| Cargo*Airfield*POL | 1 | 1 | 186.1 | 0.2166 | 0.6420 |
| Maintenance*Cargo*Airfield*POL | 1 | 1 | 4.5 | 0.0053 | 0.9423 |

airfield*POL interaction effects.  Fitting this reduced model resulted in a coefficient of determination approximately equal to the R-square value observed for the full model.  An

examination of the plot of parameter estimates shown in Figure 18 reveals that main effects airfield, POL, and maintenance remain the most important factors in terms of airfield throughput capacity. Similar to the previous model in which a combination of C-5 and C-17 aircraft received servicing, the impact of additional parking appears to have the greatest practical impact on the total number of aircraft departures. When C-5's are not included, however, POL resources replace maintenance capability as the second most significant effect. The size of the interaction plots indicates that these effects may be of limited practical significance.

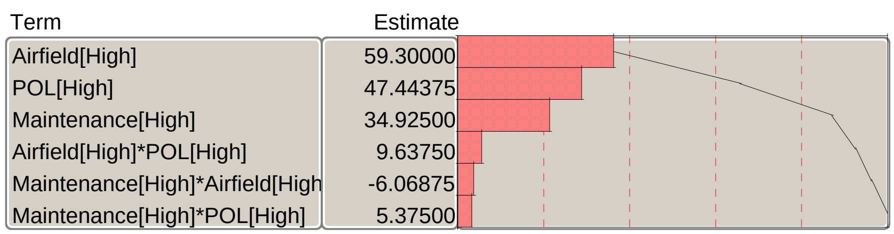


**Figure 18. Pareto Plot of Parameter Estimates- Sigonella C-17 Models**

### *C-5 Only Sigonella Model.*

The final experiment conducted during this study investigated the impact of critical base resources at NAS Sigonella on throughput of an arrival fleet of C-5 aircraft. As in earlier experiments, 20 replications of the simulation were run for each of the design points. The influence of critical base support resources on the performance measure, total aircraft departures, was initially assessed using the full factorial ANOVA procedure. The plot of residual errors against expected values was used to verify the assumption of constant variance. A normal quantile plot of the residual errors confirmed the assumption of normality was satisfied. Inspection of the summary of fit revealed an R-

square value of 0.790235. Although this ratio of the sum of squares for treatments to the sum of squares total is lower than the observed coefficient of determination found in the other scenarios, this value was deemed adequate to support investigation of important effects. Results of the full model ANOVA are presented in Table 13. Because the observed F-ration exceeds the critical value of the F-statistic, given a desired alpha value of 0.05, the null

**Table 13. ANOVA Summary- Sigonella C-5 Models**

**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 15 | 878815.8 | 58587.7 | 76.3495 |
| Error | 304 | 233278.2 | 767.4 | Prob > F |
| C. Total | 319 | 1112094.0 | | <.0001 |

hypothesis that treatment means are equal is rejected. A visual inspection was made of the treatment means in order to obtain a preliminary identification of the important factors. Figure 19 displays the cube plot of mean number of aircraft departures for each design point. The baseline model in which all factors were set to "low" resulted in the lowest average throughput from among all six experiments conducted during the course of this study. To attain a better understanding as to the possible causes of this observation, a reduced model was once again developed in order to highlight the size of important effects. Statistically significant effects were identified via the effect tests listed

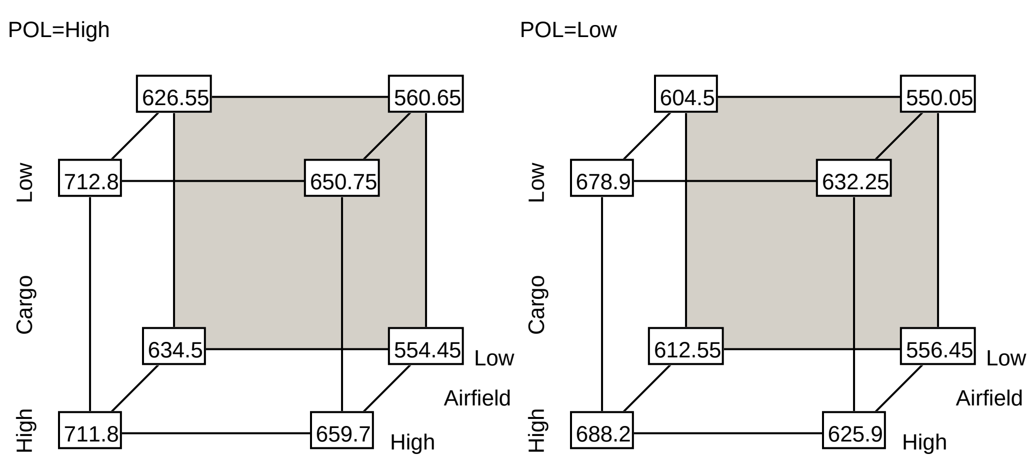

**Figure 19. Cube Plot of Treatment Means- Sigonella C-5 Models**

in Table 14. Using an alpha value of 0.05 as a threshold, the factors selected for inclusion in the reduced model included maintenance capability, airfield, and POL main effects, plus the interaction effect airfield*POL.

**Table 14. Effect Tests for Sigonella C-5 Models**

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Maintenance | 1 | 1 | 287520.20 | 374.6863 | <.0001 |
| Cargo | 1 | 1 | 918.01 | 1.1963 | 0.2749 |
| Airfield | 1 | 1 | 545490.45 | 710.8641 | <.0001 |
| POL | 1 | 1 | 32967.20 | 42.9617 | <.0001 |
| Maintenance*Cargo | 1 | 1 | 577.81 | 0.7530 | 0.3862 |
| Maintenance*Airfield | 1 | 1 | 1394.45 | 1.8172 | 0.1787 |
| Cargo*Airfield | 1 | 1 | 35.11 | 0.0458 | 0.8308 |
| Maintenance*POL | 1 | 1 | 2060.45 | 2.6851 | 0.1023 |
| Cargo*POL | 1 | 1 | 74.11 | 0.0966 | 0.7562 |
| Airfield*POL | 1 | 1 | 4089.80 | 5.3297 | 0.0216 |
| Maintenance*Cargo*Airfield | 1 | 1 | 127.51 | 0.1662 | 0.6838 |
| Maintenance*Cargo*POL | 1 | 1 | 214.51 | 0.2795 | 0.5974 |
| Maintenance*Airfield*POL | 1 | 1 | 1140.05 | 1.4857 | 0.2238 |
| Cargo*Airfield*POL | 1 | 1 | 391.61 | 0.5103 | 0.4755 |
| Maintenance*Cargo*Airfield*POL | 1 | 1 | 1814.51 | 2.3646 | 0.1252 |

The summary of fit for the reduced model provided evidence that the explained variance in the parsimonious model was nearly equivalent to the observed R-square value obtained in the full model. Therefore, the analysis continued with an examination of the Pareto plot of the parameter estimates of each of the effects included in the reduced model. Graphical representation of the effect sizes is portrayed in the Pareto plot in

Figure 20.  In this instance, the airfield and maintenance main effects appear to have the greatest impact on the number of aircraft departures.  POL also seems to possess practical significance, though noticeably less than the other main effects in this case.  The interaction effect airfield*POL, while statistically significant, does not appear to impart practical significance as evidenced by magnitude of the associated bar plot.

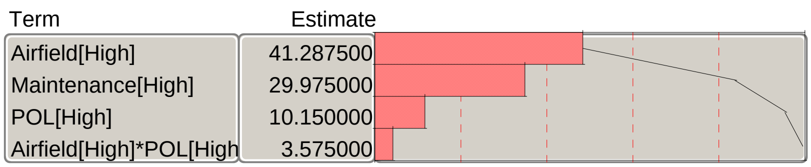


**Figure 20.  Pareto Plot of Parameter Estimates- Sigonella C-5 Models**

## Chapter Summary

This chapter has presented the results and statistical analyses performed for each of the six experiments used to investigate the relationship between critical base support factors and aircraft availability.  Model assumptions and parameters were described.  A determination of the desired number of replications for each treatment was presented, along with a graphical interpretation of the transient period associated with each of the models.  A comprehensive statistical analysis was conducted to describe the relationship between base support resources and airfield throughput for each of the experimental designs.  This analysis resulted in the identification of base support factors having the greatest practical significance. Conclusions and recommendations concerning these findings are presented in the following Chapter 5.

# V. Conclusions and Recommendations

## Chapter Overview

The purpose of this chapter is to summarize the findings of this research. Each of the four investigative questions developed for this study are addressed and supported. Limitations associated with this research are then discussed. Based on the findings associated with the investigative questions, several conclusions related to the research objective are presented. In addition, some implications for development of the proposed MAAF model are discussed. Finally, several topics for future research were identified during the course of this study. A brief description of each of these potential research topics is presented. The chapter begins by addressing each of the investigative questions.

## Investigative Question One

*What is the history regarding the study of aircraft availability within the Air Force?*

The concept of aircraft availability was investigated through a review of the literature. The determination as to the ability of the current fleet of strategic cargo aircraft to meet mission requirements is generally based on the expected availability of aircraft. However, the existing literature currently offers no precise definition as to what constitutes an available aircraft. From a maintenance perspective, an aircraft is considered available if capable of accomplishing at least one of its assigned missions.

MC rate, or the percentage of possessed hours that an aircraft is mission capable, is traditionally used to assess overall health of the fleet. A supply perspective, on the other hand, asserts that an aircraft is operationally available if not in need of a reparable component. By relating aircraft availability to expected backorders, the METRIC family of models is used to determine optimal spare parts levels for the Air Force. While a variety of definitions of aircraft available exist, the term generally refers to the ability of logistics to provide the aircraft needed to meet mission requirements.

For this study, a definition of aircraft availability was needed that addresses the short-term, point-in-time status of the aircraft necessary to support certain AMC decisions. Using a logistics perspective, therefore, aircraft availability was defined as the number of aircraft available at any time to perform a specific airlift mission or category of missions based on all pertinent operational and logistical factors.

**Investigative Question Two**

*What is the current process used by AMC to create available strategic cargo aircraft?*

A review of relevant policy and guidance was conducted to examine the means by which AMC ensures the availability of its strategic cargo aircraft fleet. The adage "the sun never sets on AMC" is a testament to the unique mission served by strategic cargo aircraft. Unlike many combat-coded aircraft that tend to deploy with the equipment and resources needed to ensure availability of aircraft, the worldwide day-to-day demands placed on the air mobility fleet present challenges in terms of the allocation of resources

necessary to sustain operations. In consideration of budgetary and geographic constraints, an air mobility network has been established that enables mobility air forces to efficiently and effectively meet mission requirements. The GAMSS is an integrated network of garrison units and deployable support forces that provides the capability to expand and contract in response to changing operational needs. Robust stateside bases, a fixed en route system, and deployable pools of resources are necessary to maximize the availability of aircraft throughout the network.

An airfield's capacity, or ability to service aircraft, is dependent on the purpose and placement of the airfield within the air mobility system. The rate at which available aircraft are created, therefore, is a function of the quantity and availability of critical resources allocated to a particular airfield.

**Investigative Question Three**

*What base support factors impact the availability of strategic cargo aircraft?*

In order to determine the base support factors that have a significant impact on aircraft availability, a review of the literature was conducted that examined relevant policy, doctrine, and research. Generally speaking, critical factors may be grouped into four broad categories: maintenance capability, material handling capability, airfield characteristics, and fueling capability. Those resources and activities necessary to repair and restore an aircraft to a serviceable condition relate to the maintenance capability of the airfield. The number and skill level of assigned maintenance personnel, and the quantity and availability of maintenance equipment and spare parts affect the types of

repair tasks that can be accomplished, as well as the amount of time necessary to complete those actions. Cargo servicing times are primarily impacted by the amount of MHE available at the airfield. In particular, the quantity and reliability of K-loaders, forklifts, and passenger buses influence the throughput rate of an airfield. Airfield characteristics encompass those physical limitations and business rules associated with an airfield. Although aircraft parking is a typical constraint, other unique airfield characteristics may include other infrastructure issues, hours of operation, and ability to accommodate aircraft possessing hazardous cargo. The final category of base support resources that impact the availability of cargo aircraft include factors related to POL. An airfield's capacity to store and dispense fuel may have a significant impact on overall ground servicing times. Bulk storage capacity, method of bulk resupply, and the availability of hydrant systems and refuel trucks are among the pertinent considerations when assessing the impact of POL resources.

**Investigative Question Four**

*What are the relationships between important base support factors?*

In order to assess the impact of varying levels of critical base support resources on airfield throughput, an experimental design was developed involving six simulation experiments. The Airfield Simulation Tool was used to model the progression of arriving cargo aircraft at an airfield through the major ground servicing activities leading to departure. Each simulation experiment involved aerial port operations at either Ramstein AB or NAS Sigonella, and one of three distinct aircraft arrival streams. For each

scenario, a full factorial experimental design was constructed to initially determine whether varying resource levels had an impact on the throughput rate of the airfield. By testing two levels for each of four categories of base resources, a design matrix consisting of 16 design points was developed representing each possible combination of factor levels. A statistically significant difference between treatment means was detected in each of the six experiments. By iteratively screening these statistically significant effects from the full model, a reduced model was created for each scenario to facilitate the identification of factors imparting practical significance on the throughput capability of the airfield.

The results of the experiments enabled the researcher to draw practical conclusions about the impact of base support resources on the availability of strategic cargo aircraft. Changes in POL capability had the greatest influence on airfield throughput in each of the Ramstein AB scenarios. Additionally, aircraft parking was identified as a practical consideration. Changes in cargo-related factors failed to demonstrate statistical or practical significance, regardless of location or aircraft arrival mix. At NAS Sigonella, airfield parking was identified as the primary throughput constraint for all aircraft arrival streams. Maintenance capability was found to be particularly important when C-5's were included in the arrival mix. POL factors also added practical significance in each of the three scenarios involving NAS Sigonella.

Because of the fidelity with which levels of base resources were determined for this study, the results discussed above may be of value to decision makers. The intent of this research, however, was not necessarily to identify airfield throughput constraints at Ramstein AB or NAS Sigonella, but to examine in broader terms the impact of base

resources on the availability of strategic cargo aircraft. The subsequent discussion presents the limitations associated with this research.

## Limitations

The conclusions that may be drawn as a result of this study are influenced by limitations related to the research methodology. First, this study investigated the impact of base support resources on the availability of aircraft. These supply-side factors of the sortie generation process represent one subset of many confounding variables that may influence the availability of aircraft. Furthermore, this study examined the impact of base support resources on the availability of strategic cargo aircraft only. The degree to which these factors influence the availability of other types of aircraft requires further study.

Second, the scope of this research was limited to the base support resources identified through the literature review as having the greatest impact on aircraft availability. The acknowledgement is made that researcher bias and limitations associated with the AST model may have resulted in the omission of certain potentially relevant base-related factors.

Finally, this design of experiments represented a "fixed effects" model because factor levels were not randomly assigned, but were purposefully selected. As such, results of the analysis may not be generalized beyond the particular values selected for the experiment. Having identified the limitations of the research, the following discussion presents the conclusions drawn as a result of this study.

## Conclusions

This study provides important information regarding the impact of base support resources on aircraft availability. Analysis of experimental results revealed that the

capability of an airfield to create available aircraft, as measured by aircraft throughput, may be influenced by the quantities of certain critical base support resources located there. While it may seem intuitively clear that the addition of important resources would yield improved throughput rates, the results of this study have shown that this supposition may be false under certain circumstances. For example, improvements in cargo servicing capability, as modeled in this study, failed to produce an observable impact on airfield throughput, regardless of location or aircraft arrival mix. This suggests that the relationship between resources and airfield capacity is not necessarily linear. Rather, the strength of the relationship depends greatly upon the nature of the demand for resources placed on the airfield by arriving aircraft, as well as the nature of the airfield itself. This study, therefore, has demonstrated the utility in using simulation and factorial design to describe the relationship between base support factors and aircraft availability.

There are several useful applications of the methodology developed for this research:

- The approach used in this study could be repeated to improve, or at least substantiate, certain base resource allocation decisions. For example, when deciding among multiple airfields for the positioning of resources, an analysis of the form used in this study may identify the location yielding the greatest benefit.
- Additionally, this methodology may be appropriate for identifying limiting factors associated with pending operations. When the number of aircraft arrivals to an airfield is projected to substantially increase, this approach

may help determine whether sufficient quantities of base resources are on hand to ensure maximum aircraft availability.

- To support long-term planning, this methodology can be implemented iteratively to help identify base infrastructure enhancements needed to accommodate future plans. For example, given a desired throughput target, infrastructure needs may be determined by running the simulation and analyzing results to discover the binding constraint. By subsequently relaxing the constraint and repeating the process, the additional resources needed to satisfy the throughput objective may be determined.

**Implications for MAAF Model Development**

In the course of conducting this research, several observations were made that may be relevant to the development of the MAAF model. First, assuming the intent of the MAAF model is to provide estimates as to the impact of proposed operations on the availability of aircraft, then the accuracy of the estimates will depend on the availability and accuracy of data related to base support resources. Real time estimates of aircraft availability may require near real time estimates of the levels of base resources at the proposed locations. Currently, however, the process for obtaining information related to base support quantities is very cumbersome. Under the current system, the data needed to drive the simulation must be obtained from multiple sources. Because resource levels at many installations are not stationary, relying on data even a few months old may yield inaccurate MAAF results.

Another concern related to the variability associated with base resource levels involved the modeling of mobility airfield operations over extended periods of time.

Because changes in the quantity of resources can alter results, the proposed MAAF model should provide the capability to modify base resource levels during the simulation run when extended runs become necessary.

### Future Research

This study used a fixed effects model in which factor values were purposefully selected by the researcher. Because the values of the independent variables were not random, the generalizability of the results of the study is limited. To enhance the external validity of the approach, a random effects model would be developed that employs levels of base support resources ranging from best case (i.e., stateside base levels), to worst case (i.e., limited en route). The objective this research would be to better describe the sensitivity of airfield throughput to changes in resource levels.

During the simulation runs in this study, the assumption was made that manpower levels were adequate to operate all equipment and perform all activities necessary to service aircraft. Because aircraft servicing times are influenced by both the quantity and skill levels of personnel performing the servicing, a study is needed that seeks to determine the impact of manning on the availability of aircraft. This research would seek to determine whether current manning authorizations are appropriate given the desired aircraft availability standard, and whether policies regarding the placement of personnel with special experience identifiers are effective.

A final topic involves the development of simulation designed to model maintenance activities and resources related to strategic cargo aircraft. Currently, the AST tool does not explicitly model aircraft maintenance operations. This effort would therefore seek to improve the fidelity of model results by disaggregating the personnel,

equipment, and activities currently represented by empirical maintenance distributions obtained through GO81.

## Appendix A: Ramstein AB, Germany

### Overview

Ramstein AB is categorized as a major en route location and serves as a central European hub in the air mobility network. Aerial Port services at Ramstein AB are provided by the 723rd Air Mobility Squadron (AMS). The following discussion summarizes the resources and infrastructure modeled in the experiments involving Ramstein AB.

### Maintenance Capability

AST does not explicitly model the activities and resources used to repair and maintain aircraft. To model the amount of ground time needed for maintenance, arriving aircraft are assigned a probability of breaking and an associated repair time based on empirical distributions obtained from the GO-81 maintenance data collection system (Cusick, 2002:6). Maintenance break rate and repair data specific to Ramstein were collected for the timeframe 1 November 2001 to 31October 2002. A summary of the Ramstein-specific break rates and repair times used in this study is provided in Table 15. For example, there is a 3.85% probability that a C-5 will require between 12 and 16 hours of maintenance upon arrival. Low factors levels represent empirical distribution data. High factor levels represent a 30% improvement in the frequency of aircraft breaks.

**Table 15. Ramstein AB Break Rate and Repair Data**

| A/C | 0-4 hours | 4-8 hours | 8-12 hours | 12-16 hours | 16-24 hours | 24-48 hours | 48-72 hours | 72-Max hours | Sum (%) |
|---|---|---|---|---|---|---|---|---|---|
| C-5 "Low" | 19.23% | 9.94% | 5.13% | 3.85% | 4.49% | 4.49% | 0.32% | 0.64% | 48.08% |
| C-5 "High" | 13.46% | 6.96% | 3.59% | 2.69% | 3.14% | 3.14% | 0.22% | 0.45% | 33.65% |
| C-17 "Low" | 32.42% | 9.39% | 3.94% | 1.72% | 1.41% | 2.63% | 0.20% | 0.40% | 52.12% |
| C-17 "High" | 22.70% | 6.58% | 2.76% | 1.20% | 0.99% | 1.84% | 0.14% | 0.28% | 36.48% |

### Cargo Resources

As noted in the global assumptions outlined in Chapter 4, the movement of cargo was simulated between the aircraft and the docks only. The number of available pallets and the number of available pallet positions on the loading docks were not considered constraints for the purposes of this study. The amount of cargo handling equipment modeled in each Ramstein AB scenario is provided in Table 16.

**Table 16. Ramstein AB Cargo Handling Equipment**

| Cargo Processing Resources | Low | High |
|---|---|---|
| Assigned 25 K loader | 2 | 3 |
| Assigned 40 K loader | 4 | 5 |
| Assigned 60 K loader | 11 | 14 |

### Airfield Characteristics

For this study, aircraft parking was limited to ramps generally reserved for strategic mobility operations and controlled by the 723 AMS. Strategic ramps 5 and 5A were modeled, in addition to Ramp 8 which accommodates aircraft possessing hot cargo. The number of parking spots modeled by ramp and level is summarized in Table 17.

**Table 17. Ramstein AB Aircraft Parking**

| Parking Ramps | Low | High |
|---|---|---|
| Ramp 5 Wide-Body Spots | 5 | 7 |
| Ramp 5 Narrow-Body Spots | 6 | 8 |
| Ramp 5A Wide-Body Spots | 6 | 8 |
| Ramp 5A Narrow-Body Equivalent Spots | 10 | 13 |
| Ramp 8 (Hot Cargo) Narrow-Body Equivalent Spots | 4 | 5 |

### POL Capability

Ramstein AB receives JP-8 aviation fuel via the Central Europe Pipeline System (CEPS) at a maximum rate of 760,320 gallons per day (528 gpm). Each of the parking ramps (Ramp 5, Ramp 5A, and Ramp 8) modeled in this study possess Type III looping hydrant systems. Pantographs are used to connect hydrant outlets to aircraft. Therefore, hydrant servicing vehicles were not modeled. Table 18 summarizes the POL factors used in the Ramstein AB scenarios.

**Table 18. Ramstein Fueling Resources**

| Fueling Resources | Low | High |
|---|---|---|
| Assigned R-11 Fuel Trucks | 8 | 10 |
| Hydrant Outlet Issue Rate (gpm) | 357 | 464 |
| Fillstand Issue Rate (gpm) | 600 | 780 |
| Commercial to Bulk Fuels Resupply Rate (gpm) | 528 | 686 |
| Bulk to Hydrant Resuppy Rate (gpm) | 565 | 735 |
| Bulk Usable Capacity (gal) | 550,809 | 716052 |
| Maximum Active Outlets | 13 | 17 |

## Appendix B: NAS Sigonella, Italy

### Overview

NAS Sigonella is categorized as a minor en route location. Most aerial port services at Sigonella are provided by local contractor through host nation support agreements. The 725$^{th}$ AMS OL-A provides limited aircraft maintenance and refueling capability. The following discussion summarizes the resources and infrastructure modeled in the experiments involving Sigonella NAS.

### Maintenance Capability

As noted in Appendix A, AST does not explicitly model the activities and resources used to repair and maintain aircraft. To model the amount of ground time needed for maintenance, arriving aircraft are assigned a probability of breaking and an associated repair time based on empirical distributions obtained from the GO-81 maintenance data collection system (Cusick, 2002:6). Maintenance break rate and repair data specific to Sigonella were collected for the timeframe 1 November 2001 to 31October 2002. A summary of the Sigonella-specific break rates and repair times used in this study is provided in Table 19.

**Table 19. NAS Sigonella Break Rate and Repair Data**

| A/C | 0-4 hours | 4-8 hours | 8-12 hours | 12-16 hours | 16-24 hours | 24-48 hours | 48-72 hours | 72-Max hours | Sum (%) |
|---|---|---|---|---|---|---|---|---|---|
| C-5 (Low) | 4.55% | 4.55% | 0.00% | 0.00% | 13.64% | 0.00% | 0.00% | 0.00% | 22.73% |
| C-5 (High) | 3.18% | 3.18% | 0.00% | 0.00% | 9.55% | 0.00% | 0.00% | 0.00% | 15.91% |
| C-17 (Low) | 2.86% | 5.71% | 0.00% | 0.00% | 2.86% | 2.86% | 2.86% | 0.00% | 17.14% |
| C-17 (High) | 2.00% | 4.00% | 0.00% | 0.00% | 2.00% | 2.00% | 2.00% | 0.00% | 12.00% |

### Cargo Resources

As noted in the global assumptions outlined in Chapter 4, the movement of cargo was simulated between the aircraft and the docks only. The number of available pallets and the number of available pallet positions on the loading docks were not considered constraints for the purposes of this study. The amount of cargo handling equipment modeled in each NAS Sigonella scenario is provided in Table 20.

**Table 20. NAS Sigonella Cargo Handling Equipment**

| Cargo Processing Resources | Low | High |
|---|---|---|
| Assigned 25 K loader | 2 | 3 |
| Assigned 40 K loader | 2 | 3 |
| Assigned 60 K loader | 3 | 4 |

### Airfield Characteristics

NAS Sigonella uses two primary parking ramps to accommodate aerial port activities. The South America Ramp possesses a Type III looping hydrant system with three outlets. Ramp 2 does not possess hydrant fueling capability but the ramp can accommodate aircraft with hot cargo. The number of parking spots modeled by ramp and level is summarized in Table 21.

**Table 21. NAS Sigonella Aircraft Parking**

| Parking Ramps | Low | High |
|---|---|---|
| South America Ramp Narrow-Body Equivalent Spots | 10 | 13 |
| ATOC Ramp Narrow Body Equivalent Spots | 2 | 3 |

### POL Capability

NAS Sigonella receives aviation fuel by pipeline at a maximum rate of 763,000 gallons per day (530 gpm). Only the South America ramp possesses hydrant-fueling capability. Pantographs are used to connect hydrant outlets to aircraft. Table 22 summarizes the POL factors used in the NAS Sigonella scenarios.

**Table 22. NAS Sigonella Fueling Resources**

| Fueling Resources | Low | High |
|---|---|---|
| Assigned Fuel Trucks | 12 | 16 |
| Hydrant Outlet Issue Rate (gpm) | 600 | 780 |
| Fillstand Issue Rate (gpm) | 600 | 780 |
| Commercial to Bulk Fuels Resupply Rate (gpm) | 530 | 689 |
| Bulk to Hydrant Resuppy Rate (gpm) | 565 | 734 |
| Bulk Usable Capacity (gal) | 500,000 | 650000 |
| Maximum Active Outlets | 3 | 4 |
| Hydrant Tank Capacity | 450,000 | 585000 |

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## Vita

Captain Christian E. Randall graduated from Cheshire High School, Cheshire, Connecticut, in June 1984. He enlisted in the U.S. Air Force in December 1987. After completing basic military training at Lackland AFB, Texas and technical training at Lowry AFB Colorado, he was assigned as a B-52 Bomb Navigation Systems Specialist, 5th Avionics Maintenance Squadron, Minot AFB, North Dakota. In September 1990, he was assigned to the 316th Organizational Maintenance Squadron, Griffiss AFB, New York as a flightline Offensive Avionics Systems Specialist. He was later assigned to the Strategic Systems Combined Test Force, Edwards AFB, California, during testing of the B-1B Conventional Mission Upgrade Program. While at Edwards, he earned a Bachelor of Science degree in Business Administration through the University of Phoenix. He attained the rank of Technical Sergeant before being selected for Officer Training School in November 1999.

After receiving his commission, Captain Randall was assigned to Headquarters, First Air Force, Tyndall AFB, Florida, as a Logistics Plans officer. While at Tyndall, he served as the Joint Operations Planning and Execution System (JOPES) Cell OIC for the CONUS NORAD Region Air Operations Center during Operation Noble Eagle. In August 2002, he entered the Graduate Logistics Management program at the Air Force Institute of Technology. Upon graduation, he will be assigned to the Air Force Research Laboratory, Human Effectiveness Directorate, Wright-Patterson AFB, Ohio.

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**14. ABSTRACT**

Over the past decade, the nation's military has grown increasingly reliant upon strategic airlift capability. In the post-Cold War era, military doctrine has shifted from an inventory policy favoring overseas basing and prepositioned materiel to a transportation policy that concentrates on the rapid deployment of forces. Much of the responsibility for providing timely global mobility belongs to the Air Mobility Command (AMC) and its fleet of strategic cargo aircraft. The AMC Directorate of Logistics is responsible for ensuring AMC aircraft are available to accomplish the mission. Currently, however, the organization lacks an objective tool for assessing the impact of proposed operations on the health of the fleet. To improve this process, the Directorate has initiated the development of a Mobility Aircraft Availability Forecast (MAAF) simulation model designed to identify alternatives and associated impacts on aircraft availability, manpower, and cost.

This research seeks to assist the MAAF development effort by identifying and demonstrating how different base support factors impact the availability of AMC aircraft. To address this research objective, multiple simulation models were developed using the Airfield Simulation Tool (AST). The impact of changing resource levels was assessed for different locations and aircraft arrival profiles. Results of this research yield practical implications for developers of the MAAF model and air mobility planners.

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